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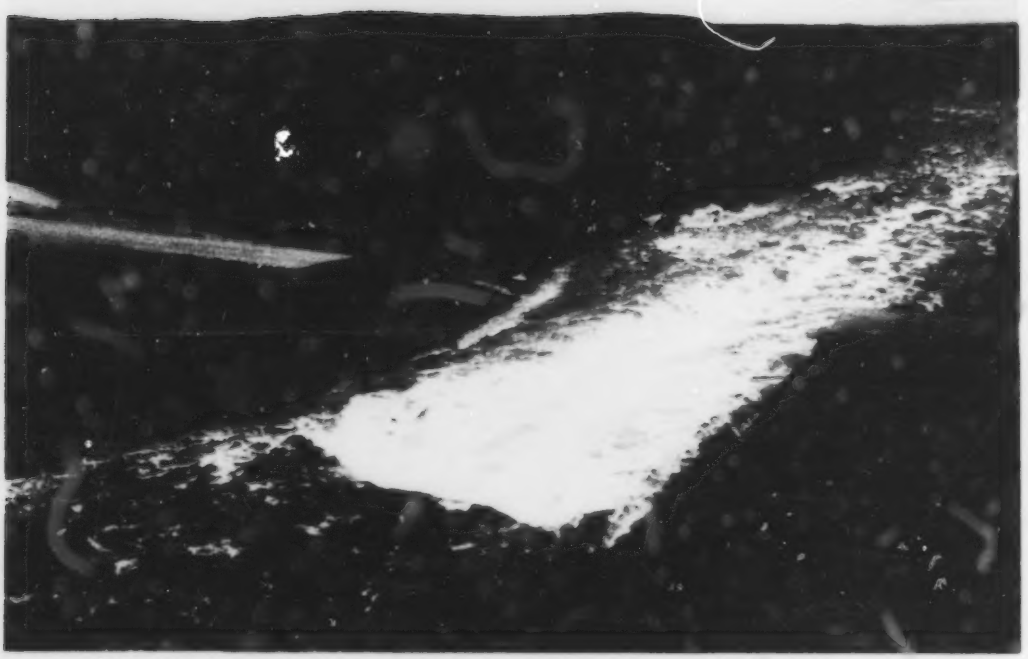
An Historic N.W.T. Flood

1988 Flooding in the Liard and Mackenzie River Basins



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An Historic N.W.T. Flood

1988 Flooding in the Liard and Mackenzie River Basins

by

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Studies and Hydrology Section

With special contributions

from

Atmospheric Environment Service
Environment Canada

Yellowknife, N.W.T.
January 1992

N.W.T. Programs
Inland Waters Directorate
Conservation & Protection
Western & Northern Region
Environment Canada

C&P-IWD-NWT-91-001

93-01679/

Cover photograph courtesy of Pat Wood, WSC-Fort Simpson.

Washout of Liard Highway Poplar River bridge on July 3, 1988. Twin 5.5 m diameter culverts and about 10 m of fill were washed out the morning of July 1 by high flood flows.

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ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of the many individuals and agencies whose advice and assistance made this report possible, including: Eric Bussey, NWT Emergency Measures Organization, Gordon Barber, Andrew Gamble, and Tony MacAlpine, Department of Transportation, all of the Government of the NWT; John Hayes, Interprovincial Pipe Lines Ltd.; Jack Symes, Esso Resources; Cameron Clements and Jim Hamblin of Northern Transportation Company Ltd.; Al Dion, Canadian Coast Guard, Transport Canada; Dr. Kaye MacInnes, Land Resources Division, Indian and Northern Affairs Canada; and Steve Langdon, Nahanni Park, Canadian Parks Service, Environment Canada.

Inland Waters Directorate personnel who collected field data and photographs of the floods included Water Survey of Canada staffers Pat Wood, Gerald Wright, and Roger Pilling of Fort Simpson, Murray Jones and Blair Thorson of Fort Smith, Herb Wood, Moe Hansen, George Lennie, and Wade Hanna of Inuvik, and Bill Aitken and Al Wilson of the NWT Programs office, Yellowknife. NWT Programs COOP student Colin Rogers prepared updates on sediment loads of area rivers, and Malcolm Conly, Scott McDonald, and Paul Squires reviewed the draft report.

Gary Burke, formerly with the Yellowknife weather office (now with Arctic Weather Centre, Environment Canada, Edmonton) prepared an analysis of the 1988 storms (see Burke,1989) and worked on initial versions of this report with Henry Westermann, formerly with Inland Waters Directorate (now with Environmental Protection, Environment Canada, Yellowknife). Neil Parker of Atmospheric Environment Service, Environment Canada, Edmonton, summarized storm analyses, which the authors incorporated into sections 3.1 and 4.1 of this report.

Finally, thanks are due NWT Programs' secretary Marcia Moss for her typing of early drafts of the report, contractor Janet Troje for drafting figures, and Paul Squires and Migs Lovlin for their assistance in preparing the final document for printing.

SUMMARY

This report documents severe weather conditions and resulting floods during June and July 1988 in the southwestern Northwest Territories. Prior ground moisture conditions, local relief, amount and distribution of precipitation, storm path, and watershed characteristics were found to be important factors in the magnitude and timing of the major floods which occurred in area river basins.

Damages to facilities and services of various government agencies and private sector companies totalled more than $6 million. The most severe damages were to NWT highways ($3.25 million, plus undetermined costs due to Liard Highway closure) and the Interprovincial Pipe Line Ltd. oil line between Norman Wells and Zama Lake ($1.8 million). The need for warnings of such floods was demonstrated by the washing away of fuel, vehicles, and other material stored on docks at Norman Wells.

While the events of 1988 were unusual, similar storms and floods can occur with little warning during summer months of any year. Ongoing monitoring of real time data networks, interpretation of streamflow data and a timely public advisory process are therefore required to warn area residents of future floods.

RÉSUMÉ

Ce rapport documente les conditions atmosphèriques sévères et les innondations résultantes durant les mois de juin et juillet 1988 dans le sud-ouest des Territoires du Nord Ouest. Les conditions précèdentes d'humidité du sol, le relief local, le montant et la distribution de la précipitation, le chemin de l'orage, et les caractèristiques des bassins hydrographiques ont été les facteurs importants dans la magnitude et l'engrenage des innondations majeures qui se sont produites dans les bassins fluviales de la région.

Les dommages aux facilitées et services des diverse agences gouvernmentales et des compagnies du secteur privé ont totaliser plus de $6 millions. Les dommages les plus sévères ont été aux autoroutes des TNO ($3.25 millions en plus des coûts indeterminés due à la fermeture de l'autoroute Liard) et à la ligne de pétrole International Pipe Line Ltd. entre Norman Wells et Zamma Lake ($1.8 millions). Le besoin des prévisions de telles innondations a été demontré par l'emportement dans le fleuve du pétrole en barril, des véhicules, et d'autres matériaux entreposés sur les quais à Norman Wells.

Même si les évènements de 1988 sont rares, des orages et des innondations semblables peuvent se manifester avec peu d'avertissement durant les mois d'été de n'importe quelle année. Un service d'écoute continu des données en temps réel, une interpretation de données des débits des fleuves, et un processus d'avis publique à propos sont alors requis pour avertir les résidents de la région d'innondations futures.

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1.0 INTRODUCTION

From June 28 to July 3, 1988, unusual weather conditions produced a major rainstorm over northeastern British Columbia, northwestern Alberta, and the southwestern part of the Northwest Territories. Weather station records show that precipitation before and during the storm exceeded historic averages for June and July. The resulting storm runoff produced high flows on the Hay River, on the Liard River and its tributaries, and on the Mackenzie River downstream from its confluence with the Liard River.

The rainfall and resulting high flows caused substantial damages throughout the area. Washouts occurred at many stream crossings on the Liard (NWT No. 7) and Mackenzie (NWT No. 1) highways. A section of pipe on the Interprovincial Pipe Line (IPL) Norman Wells to Zama Lake pipeline was exposed and a stream guidebank at another location washed out. Public and company docks on the Mackenzie River at Norman Wells and some Esso Resources island oilfield facilities were flooded, and approximately 600 barrels of fuel oil and four vehicles were washed away.

A second major rainstorm occurred in the Liard River basin between July 11 and July 15, 1988. This second event, though not as intense as the first, produced the highest flows ever recorded on the Liard River. Flooding from this second storm resulted in the evacuation of elders from the settlement of Nahanni Butte. Slumping of mountain slopes near Nahanni Butte, caused by the heavy rain, contributed to the permanent closure of the Nahanni Butte warden station of the Canadian Parks Service.

While mountain rivers in the area commonly produce their highest flows during rainstorm events, flow records for area lowland rivers indicate that spring snowmelt runoff and ice jams are generally responsible for extreme flood events in these basins. The 1988 storms also produced historic peak flows for these rivers.

The floods also increased the transport of sediment, redistributed existing channel materials, and caused significant downstream changes along the Mackenzie River and in the Mackenzie Delta.

Damages due to the flood event are estimated at about $6 million, and have raised concerns about the need for improved warnings of floods for communities and industrial concerns in the area.

Floods such as the July 1988 events require documentation and analyses because they can cause extensive damage and endanger lives. Flood studies provide important information required to assess existing water resource data networks, to evaluate the effectiveness of current flood warning and damage reduction measures, and to facilitate planning for new development.

The objective of this report is to document the causes, magnitudes, and impacts of 1988 floods.

2.0 RIVER BASIN AND FLOW CHARACTERISTICS

2.1 General

The size and nature of floods in a major drainage basin are determined by the meteorologic events producing runoff, moisture conditions in the basin prior to the flood, and physical characteristics of the basin.

The potential for significant basin runoff is controlled by the intensity, duration, and path of summer rainstorms. Rainfall intensity and land surface characteristics control how much water will infiltrate into the ground and how much will run over the ground surface and into channels. As the duration of a storm increases, larger and larger areas of the basin contribute runoff. Longer-duration storms are necessary to produce major floods on large watersheds because of the time it takes for runoff to travel from headwater areas to the basin mouth.

Basin soil moisture conditions determine how much initial precipitation infiltrates into the ground, and how much is stored in swamps, ponds, and lakes. Basin physical characteristics determine how precipitation will be transformed into runoff and how runoff will be modified as it moves downstream. Factors which influence the response of a basin to storms include land use, surface slopes, basin shape, soil types, presence of permafrost, vegetation types, the presence of lakes and swamps, and channel storage characteristics.

2.2 Mackenzie River Basin

Figure 1 shows the portion of the Mackenzie River basin situated in the Northwest Territories. The Liard River and tributaries of the Mackenzie River draining the Mackenzie Mountains to the west are the primary sources of floods in the lower Mackenzie River basin.

Major runoff events and floods also occur upstream from Great Slave Lake, in the Peace, Athabasca, Hay, and other river basins, but downstream effects of these floods are dampened by the large

Figure 1. Stream gauging stations in the area affected by 1988 storms (refer to Table 4 for station names).

storage capacity of Great Slave Lake. During years of high Slave River basin runoff, Great Slave Lake stores and gradually releases Slave River water. Although Great Slave Lake significantly decreases the size of floods from upstream areas, outflows still contribute to flows and floods downstream from the lake.

a) Mackenzie River above Liard Confluence

Runoff from this area includes outflows from Great Slave Lake and the flow of tributaries entering the Mackenzie River between Great Slave Lake and the Liard River. The latter area consists of flat poorly-drained Devonian-era sediments covered with boreal forest, muskeg, and wetland. The major tributaries are the Kakisa (Station #07UC001), Trout (10FA002) and Jean Marie (10FB005) south of the Mackenzie River, and the Horn and Rabbitskin to the north.

The three basins south of the Mackenzie River are gauged year-round by field staff of the Water Survey of Canada, Environment Canada. The highest annual flows in these basins are generally produced by spring snowmelt in May or early June. Flows in the Kakisa and the Trout river basins, which contain large lakes, generally decrease gradually after their snowmelt peaks, with very few significant summer rainstorm floods. The smaller Jean Marie basin is more responsive to rainfall events, with several significant summer and fall rainstorm peaks evident in the flow records.

Basins draining the north side of the Mackenzie River are not gauged. Runoff from these areas is assumed to be similar in character to that of the Jean Marie River due to the similarity in basin sizes and lack of major lakes.

Great Slave Lake outflows (10FB001) did not change during the period, as the Hay River (07OB001) was the only tributary to Great Slave Lake affected by the July 1988 storms. The Hay River drains parts of British Columbia, Alberta, and the Northwest

Territories, and is similar in character to the Trout and Kakisa rivers to the northwest, but without major lake control in the lower part of the basin. Spring runoff generally produces the highest flows each year, but intense summer rainstorms occasionally produce summer floods exceeding spring flood flows in years with low snowmelt peaks (Jasper, 1983; Wedel, 1985). As stated above, these summer storms generally have little effect on the Mackenzie River downstream from Great Slave Lake because of the large storage capacity of the lake.

b) Liard River

The Liard River basin drains portions of British Columbia, Alberta, Yukon, and the NWT. It has a drainage area of about 275,000 km^2 at the mouth, and is the largest contributor of water and suspended sediment to the Mackenzie River during spring breakup and major floods (Mackenzie River Basin Committee, 1981).

The Liard River rises in the Pelly Mountains of the Yukon and flows southeast into British Columbia, passing through part of the Rocky Mountains. After leaving the mountains, it flows northeast across a plains area consisting of soft sediments to confluences with the Fort Nelson River from the south and the South Nahanni River from the west, and on to its junction with the Mackenzie River from the east at Fort Simpson.

Annual runoff from the basin is characterized by a short intense period of spring snowmelt and ice breakup in the middle and lower Liard River, followed by snowmelt from the mountainous headwater areas to the south and west. The highest flows of record have been produced by intense rainfall events in late spring and early summer, when basin soil moisture is high due to snowmelt or earlier rainfall events. Significant floods occur throughout the summer, when moist maritime airmasses move into the area (Grey, 1981). Dramatic increases in suspended sediment loads and debris in the lower Liard and Mackenzie rivers are important consequences of these events.

The Water Survey of Canada gauges the mainstem Liard River at two locations in the NWT (10ED001 & 10ED002), and three tributaries, the South Nahanni (10EA001, 10EA003 & 10EC001) and Birch (10ED003) rivers, and Rabbit Creek (10ED006). The world-famous Virginia Falls and Nahanni National Park are located in the South Nahanni River basin.

c) **Mackenzie River below Liard Confluence**

Tributaries of the Mackenzie River as far downstream from Fort Simpson as Fort Good Hope were affected by the storm. Major rivers affected include the North Nahanni, Redstone, Keele, Carcajou and Mountain rivers draining the Mackenzie Mountains to the west, and the Willowlake, Blackwater, Big Smith and Ochre rivers draining the low-lying plains to the east. In 1988, hydrometric gauges were operated on the Redstone (10HB005), Carcajou (10KB001), Mountain (10KC001), upper Keele (the Twitya River, 10HA003), Wrigley (10HB003), Willowlake (10GB006), and Blackwater (10HC006, not on map) rivers, as well as on the Mackenzie River near Wrigley (10HC001), at Norman Wells (10KA001), and at Arctic Red River (10LC014), and on the Great Bear River at the outlet of Great Bear Lake (10JC003).

The western rivers drain fairly steep mature mountains, primarily consisting of folded limestones and dolomites. They flow in wide alluvium-filled glaciated mountain valleys before passing across the plains to the Mackenzie River (Bostock, 1948; Norris et al, 1963; Douglas et al, 1970). Vegetation in lower-lying areas consists of boreal forest, with alpine tundra/taiga and weathered rock surfaces at higher elevations. The rivers are responsive to both spring snowmelt and summer rainstorms. Major floods have generally occurred due to rain on melting snowpacks or major summer rainfall systems (MacKay et al, 1973).

The eastern rivers drain a plains region, bordered to the east by the Canadian Shield. Terrain consists of sedimentary rocks overlain by glacial tills and generally flat poorly-drained boreal forest, muskeg, and small lakes (GNWT/IWD, 1984). Soil

development is limited, and discontinuous permafrost lies under much of the area. Streamflow data for the Willowlake, Blackwater, Big Smith, and other gauged rivers of the area indicate that the highest flows generally occur during the spring snowmelt period. Significant peaks rarely result from summer rainstorms because the response of basins to rainfall is dampened by surface storage.

3.0 CHRONOLOGY OF THE 1988 FLOODS

3.1 Weather Conditions

a) Pre-Storm Conditions and Storm Summary

The three-week period preceding the July 1988 floods was characterized by unsettled weather conditions, as a disturbance in the Gulf of Alaska steered moist unstable air inland. Showers and thunderstorms which developed over the area resulted in some heavy local rainfall. This rainfall increased soil moisture content, and set the stage for high runoff from subsequent storms.

During the period from June 29 to July 3, 1988, a major low pressure system developed over central Alberta and intensified as it moved northward. Warm moist air of the system was forced against the eastern slopes of the mountains by easterly winds, producing orographic lifting of the airmass, further enhancing precipitation.

During the period from July 11 to July 15, 1988, a second Pacific disturbance moved into southern Alberta and split into two systems. The smaller storm then moved northward into the southern part of the Mackenzie basin. While this storm did not produce as much precipitation as the first, it did result in major convective rainfalls and high flows.

b) The June 29 to July 3 Storm

A major synoptic scale disturbance developed over central Alberta at the end of June, and intensified as it moved northward. Figure 2 shows the path followed by the main centre at the 50 kPa[1] level (kiloPascales, at about 5575 m altitude), while Figure 3 shows the surface air pressure analysis at 00:00 UTC (Universal Time Coordinated) on July 1, 1988 (equivalent to 18:00 MDT, or Mountain Daylight Time, on June 30). The main upper air feature remained anchored in the Gulf of Alaska while the storm centre

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[1] Normal surface atmospheric pressure is 100 kPa; 50 kPa is the pressure mid-point of the atmosphere.

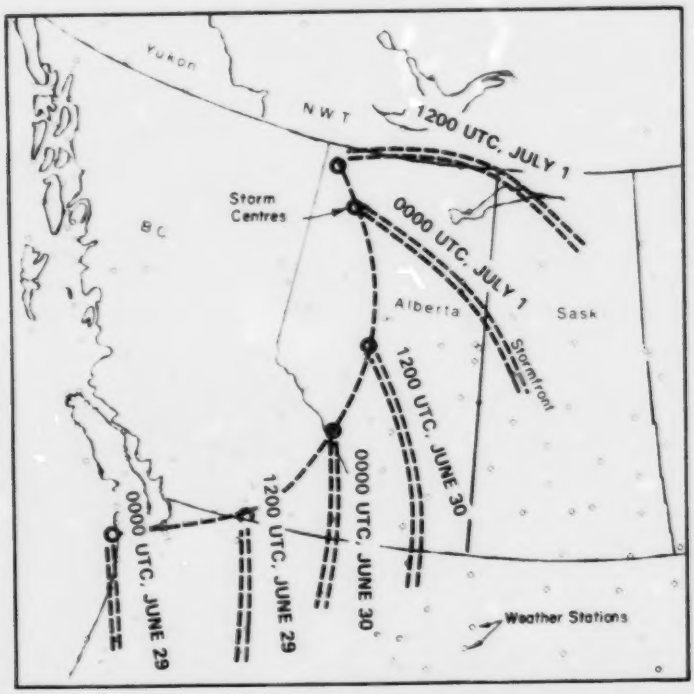


Figure 2. Path of 50 kPa (mid-atmosphere) storm centre and trough from June 29 to July 1, 1988.

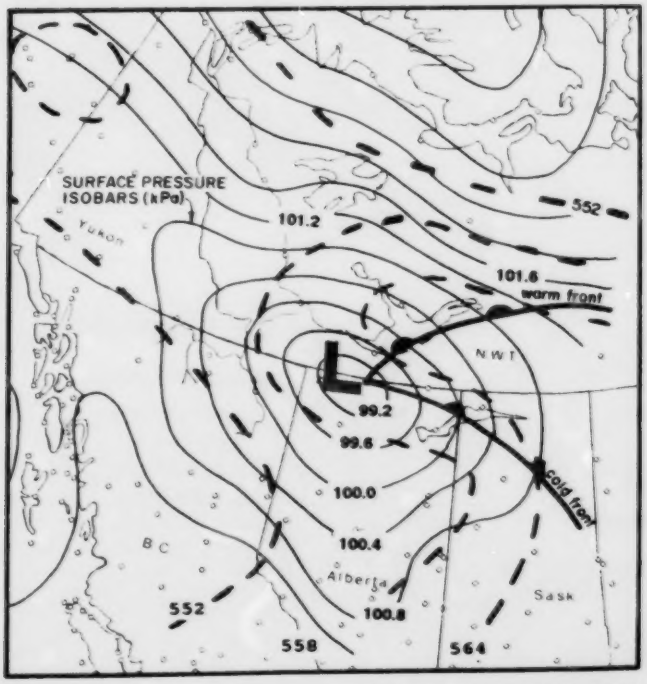


Figure 3. Surface analysis and 100 to 50 kPa thicknesses (dm, or tens of metres) for 00:00 UTC July 1, 1988.

rotated around this larger system through southern British Columbia, Alberta, and southwestern NWT.

The surface low developed over Alberta as the upper feature moved east of the mountains (about 00:00 UTC on June 30, Figure 2) and continued to intensify as it rotated northward. Dashed lines on Figure 3 are lines of equal thickness (dm, or 10's of m) of the atmospheric layer between 100 and 50 kPa (the greater the thickness from the earth's surface and atmospheric mid-point, the warmer the air). The position of these lines (especially the 558 and 564 dm isolines) around the low pressure centre(L on Figure 3) shows that warm stable air had curled around the north side of the system. Weather satellite images and data from instrumented balloon ascents indicated that the airmass was moist.

In addition to the above-described dynamics of the system, the easterly circulation north of the storm centre produced additional orographic lift as the airmass approached the

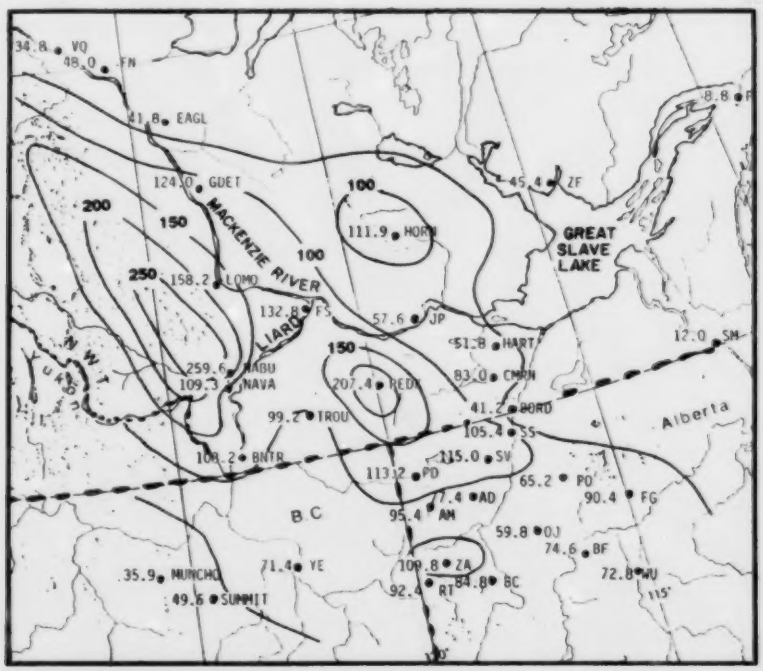


Figure 4. Total precipitation (mm) for the period June 29 to July 3, 1988.

mountains and was forced over them. This combination of forces contributed to the precipitation pattern displayed on Figure 4 (and Table 1, pg. 34).

The relationship between higher terrain and greater precipitation totals is apparent from precipitation amounts reported over the eastern slopes of the Mackenzie and Caribou mountains and in the Cameron Hills and the Horn Plateau areas. A maximum of 259.6 mm of rain was reported at Nahanni Butte, but even higher amounts may have fallen in the mountain areas. For example, the nearby Nahanni Valley site a few kilometres from the mountains at a lower elevation received 150.3 mm less precipitation.

c) **The July 11 to July 15 Storm**

Barely one week after the first storm had ended, it appeared as if history was about to repeat itself as another weather system of Pacific origin moved into the northwestern United States and subsequently moved northeastward into Alberta. Unlike the previous storm, however, this one behaved more conventionally, by splitting into a minor portion that moved northward while the main portion continued eastward.

Figure 5 presents the surface air pressure analysis and 100 to 50 kPa (surface to mid-atmospheric pressure) thickness pattern for 00:00 UTC July 13, 1988 (18:00 MDT July 12). The wider spread between lines of equal surface pressure on Figure 3, in comparison to Figure 5, indicates that the second system was weaker. Since there was not as much warm air wrapped around this system, the airmass was more unstable. Showers and thunderstorms were responsible for the local rainfall, as indicated by total precipitation amounts on Figure 6.

The highest totals occurred along the surface trough line, whereas strong easterly upslope circulation of warm air on the north side of the previous system produced greater precipitation in the Mackenzie Mountains. Daily precipitation totals were not unusually high, but storm totals were significant over the

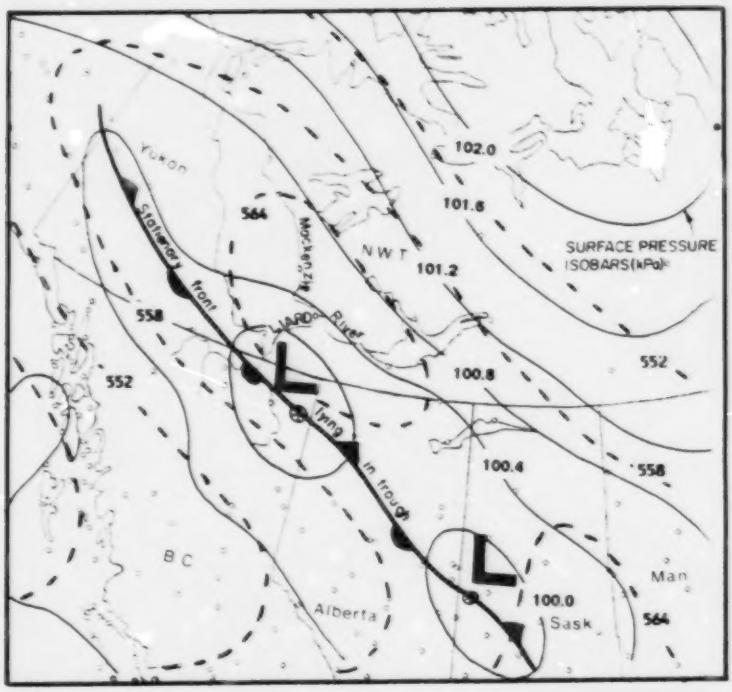


Figure 5. Surface analysis and 100 to 50 kPa thicknesses (dm) for 00:00 UTC July 13, 1988.

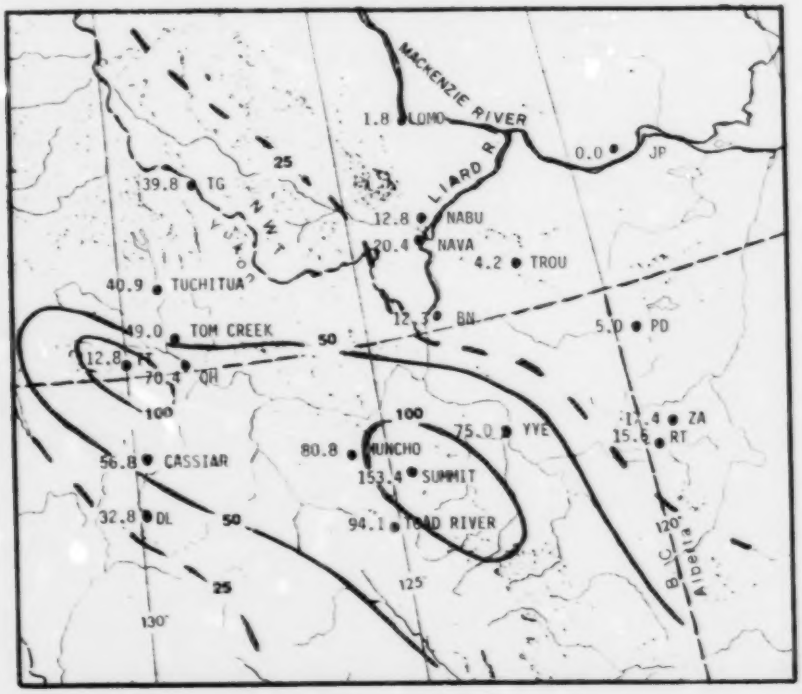


Figure 6. Total precipitation (mm) for the period July 11 to July 15, 1988.

western and southern parts of the Liard basin, near Watson Lake and Fort Nelson.

3.2 Flood Progression

Immediately prior to the two storms, rivers gauged by the Water Survey of Canada (WSC), Environment Canada in the affected area were in normal recession from spring runoff peaks. Streamflow values were above normal for this time of year, however, due to above-normal June precipitation.

The WSC station on the small 93 km^2 Rabbit Creek watershed near Fort Liard was the first to record a rise in water levels during the late June/early July storm, on the morning of June 29. By the morning of June 30, most of the tributaries of the Liard and Mackenzie rivers were showing a steady rise. As indicated on Figure 7, only stations on the Mackenzie River and the Liard River had not shown a rise in water level at this point in time.

On July 1, the flashy mountain rivers (the Redstone, Carcajou, Sahndaa, and Root) rose dramatically and peaked. The Liard River and the Mackenzie River at Norman Wells were starting to rise, while the remaining tributaries continued to rise steadily. The Wrigley River flooded, eroding the stream bank and destroying the WSC station near the river mouth.

Another mountain river, the South Nahanni, peaked early on July 2, as did the Willowlake and Birch rivers and Rabbit Creek in flatter terrain to the south and east. By the end of July 3, most of the gauged rivers had peaked. At 22:30 on July 3, the mainstem Mackenzie River at Norman Wells reached the maximum flow ever recorded (33,700 m^3/s). The first rise in water level of the Mackenzie River downstream at Arctic Red River was also recorded on July 3.

On July 4, the Trout River, with its tremendous lake storage, and the Liard River at Fort Liard reached their peak flows. After a

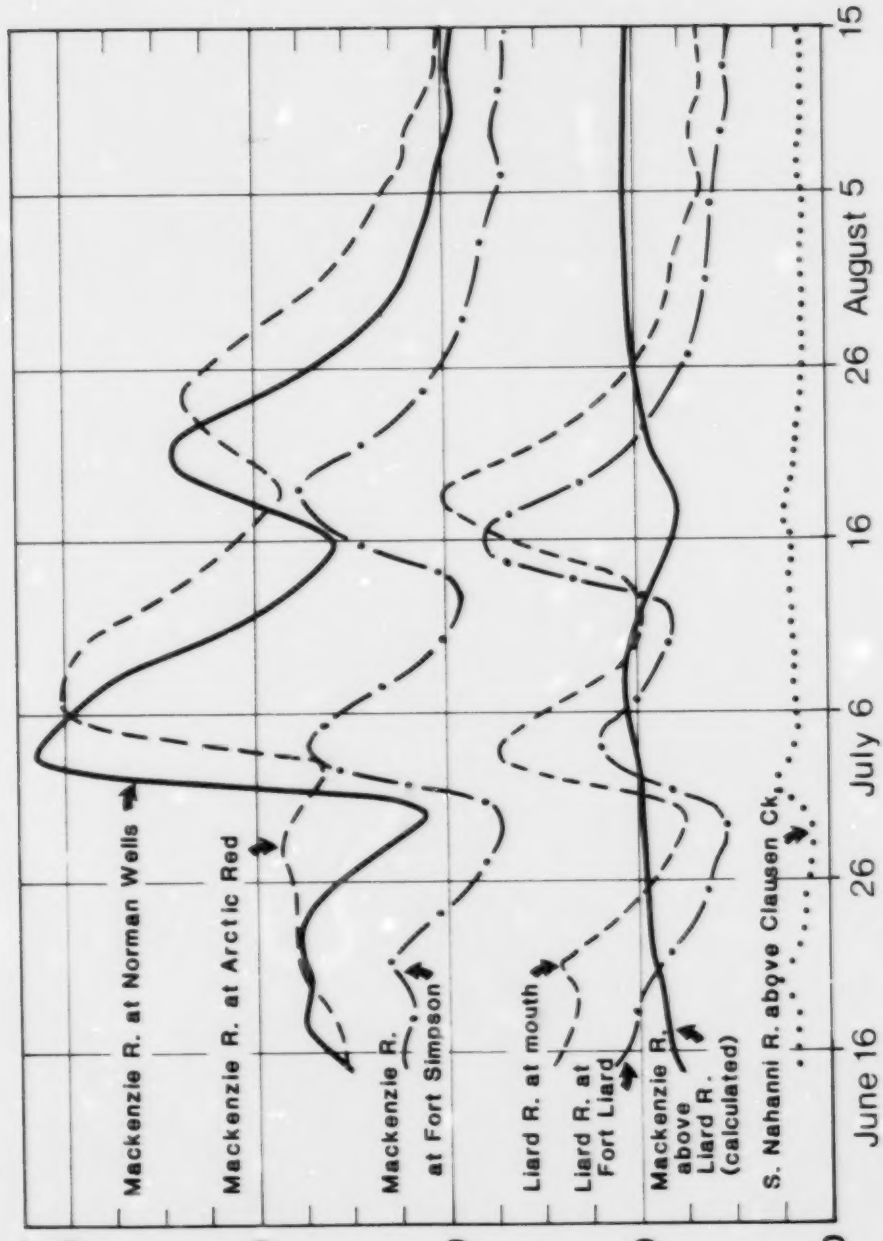


Figure 7. Liard and Mackenzie river hydrographs for the period June to August 1988.

minor peak on July 1, the Mountain River rose to a second, higher peak on July 6, probably the result of isolated heavy precipitation in its mountainous headwaters. Flood waters also peaked on the Mackenzie River at Arctic Red River on July 6.

Water levels for the Hay River Alberta/NWT border station showed a steady but delayed rise to a peak on July 8, due to storage of storm waters in wetlands in the western headwater/Zama Lake area. The peak reached the community of Hay River on July 9, resulting in the highest flow ever recorded at this location.

Peak water levels occurred at Inuvik in the Mackenzie Delta early on July 11, approximately 12 days after the storm began. By this time the second weather system was establishing itself over northeastern British Columbia and the southern Yukon, affecting primarily the Liard Basin.

On July 16, this second storm event, combined with the saturated condition of the Liard River basin, produced a second flood peak (the highest recorded in 23 years) on the Liard River at Fort Liard. Further precipitation and inflow from the lower reaches of the Liard River basin produced a record peak flow at the mouth of the Liard late on July 18. The significance of this second flood diminished as it passed down the Mackenzie River, due to the absence of major tributary flooding. Mackenzie River water levels peaked on July 19 at Fort Simpson, on July 21 at Norman Wells, and on July 24 at Arctic Red River.

3.3 Flood Damages

Flood damages occurred at the Norman Wells oilfield operations of Esso Resources, on NWT Highways No. 1 and No. 7, at points along the Interprovincial Pipe Line (IPL) pipeline from Norman Wells to Zama Lake, to Transport Canada's river navigation markers on the Mackenzie River, at Water Survey of Canada gauging facilities, and in the community of Nahanni Butte.

Esso Resources operates a number of oil wells on natural and man-

made islands in the Mackenzie River at Norman Wells (Figure 8a). Approximately 100 wells are located on two natural islands, and 14 to 17 wells on each of six artificial islands. Total oilfield production at the time of the flood was approximately 4,450 m^3 of oil per day.

High water levels produced by the 1988 floods resulted in the shutdown of wells on low-lying portions of the islands for 34 days, delaying production of 34,000 m^3 of oil. Two large shale-fill causeways on the natural islands were eroded, and three portable docks on the Norman Wells shoreline were washed away. Four company vehicles were washed away and another damaged. The vehicles and docks were later recovered. Erosion on one of the natural islands at Norman Wells exposed approximately 100 metres of pipeline, which required reburial. The total cost for repairs, equipment replacement, delayed production, salaries, and other items was estimated at $418,000 (H. Irwin, 1988 and J. Symes, 1991; personal communications).

The **Northern Transportation Company Ltd.** (NTCL) lost 594 barrels of fuel oil temporarily stored on the docks at Norman Wells (see Figure 8a) for delivery to communities along the Mackenzie River. The drums were strewn far downstream along the river. Esso Resources and NTCL suffered considerable adverse publicity over the incident, due to concerns over possible environmental pollution. While over 77% of the barrels were recovered by NTCL, losses exceeded $200,000, including $141,000 worth of drummed fuel and cargo, and $60,000 for the recovery program (J. Hamblin,1989; C. Clement, 1990, personal communication).

Interprovincial Pipe Line Ltd. (IPL) suffered major damage at stream crossings on its pipeline from Norman Wells to Zama, Alberta. A river guidebank at Hodgson Creek near Wrigley was washed out, and the pipe under the Ochre River north of Wrigley was exposed (figures 8b, c, and d; and IPL, 1988). The cost of extending deep burial of the pipeline at both sites and special

reclamation measures at other locations was estimated at $1,800,000 (J. Hayes, 1991, personal communication).

Channels of other small rivers, such as Little Smith Creek, Saline River, Steep Creek, and others south of Norman Wells underwent significant modification (Egginton, 1989), but did not threaten the pipeline.

NWT Highways No. 1 (Mackenzie Hwy) and No. 7 (Liard Hwy), maintained by the Government of NWT, Department of Transport, experienced considerable damage and disruption to service. The Liard Highway connecting Fort Liard to the Mackenzie Highway was washed out at a number of points. At the Poplar River crossing, two 5.5 m diameter culverts were removed by high flows (see photographs, figures 8e and f), transported 500 m downstream, and left battered beyond repair. The highway remained closed for several months until repairs could be made, including the installation of a temporary Bailey bridge at the Poplar River.

The Mackenzie Highway between Hay River and Fort Simpson was not as severely affected, and service was restored within a few days (P. Wood, 1991, personal communication). Highway ferry operations at the Liard River and other crossings experienced only minor damage, due to washouts of ferry landings (T. MacAlpine, 1991, personal communication). Other highway flood damages included minor erosion at culverts, minor roadbed washouts, erosion and scour at bridge abutments, and culvert washouts (figures 8g, h, and i).

Estimated highway damages totalled approximately $3.25 million, including $750,000 for repairs to bridges and culverts, roadbed reconstruction, and installation of a temporary Poplar River crossing, and $2.5 million for future construction of a permanent Poplar River bridge (G. Barber and A. Gamble, 1988; personal communications).

The **Canadian Coast Guard, Transport Canada**, operates navigation

aids for vessels on the Athabasca/Mackenzie Waterway. An average of 107 buoys are replaced each year along the 1,100 km of the Mackenzie River between Great Slave Lake and the Beaufort Sea, due to floods and debris in the river (Figure 8j). Due to the short duration of the shipping season, the distances involved, and the availability of only three buoy tender vessels, a large inventory of backup buoys anchors and chains is cached at points along the river, to replace lost channel markers.

The Coast Guard reported the loss of 298 buoys during the 1988 floods, which "produced the highest water levels on the Mackenzie River since observations were begun some 54 years ago" (memo referenced by A. Dion, 1991). The cost of replacing navigation hardware after the July floods totalled $245,800, including about $150,000 for buoys, $53,000 for associated hardware, and $42,000 for shipping and other charges, plus uncosted extra 1988 maintenance (A. Dion, 1991, personal communication).

The **Village of Nahanni Butte** was threatened by flooding during the second major storm in the upper Liard River basin. On July 15, rising waters approached low-lying areas of the community. On July 16, Water Survey of Canada personnel warned the community of the possibility of even higher water levels as the flood passed through the basin. The next day, municipal leaders of Nahanni Butte requested that the community be put on flood alert, and evacuation arrangements were made with the NWT Emergency Measures Organization and the community.

By 22:50 on July 17, low-lying areas in the community had flooded (Figure 8k) and evacuation of community elders was requested. A plane left Fort Simpson for Nahanni Butte at 23:30 on July 17 to fly 18 elders to Fort Liard for billeting. The remaining residents camped on higher ground near the community. On July 19, with water levels receding and no further precipitation predicted, the elders were flown back to Nahanni Butte.

Actual damages reported in the community were minimal. One house

and the community's two-bay garage were inundated, the floor of the nursing station was flooded, and water reached the level of the floor of the RCMP patrol cabin. The community well was flooded and residents were advised to boil their drinking water as a precautionary measure. The major cost of the flood was $2,900 for the evacuation aircraft charters (E. Bussey, 1988, personal communication). A number of small boats and canoes were also reported lost, but no information on their value is available (P. Wood, 1991, personal communication).

At **Fort Simpson**, the prolonged period of high water levels on the Mackenzie River and the heavy rains saturated the silty river banks. This increased pore water pressures in the unfrozen sediments, causing slumping (Figure 81). Concern about this new erosion and the safety of river bank areas of the community led to the community closing the river bank road, Mackenzie Drive, and having a $12,000 engineering evaluation of bank stability carried out (P. Wood, 1991, personal communication). Potter Consultants (1991) recommended erosion control and surface drainage improvements to protect banks from floods and long-term slumping, at an estimated cost of $320,000.

The **Water Survey of Canada, Environment Canada,** lost equipment valued at more than $25,000. The Wrigley River near the mouth station was completely destroyed, due to the erosion of 15 m of river bank over a distance of 100 m (Figure 8m). On the Root River, water rose 8.2 m, covering the floor of the gauge shelter, and washed out the water level orifice line (Figure 8n). Miscellaneous stream and sediment survey equipment was also lost during the flood monitoring effort.

In addition, the NWT Programs office spent $45,000 in special activities to document the unique flood events. Since replacement funds to cover regularly scheduled work over the rest of the year could not be found, normal 1988 water survey activities in the Northwest Territories were affected (R. S. McDonald, 1991, personal communication).

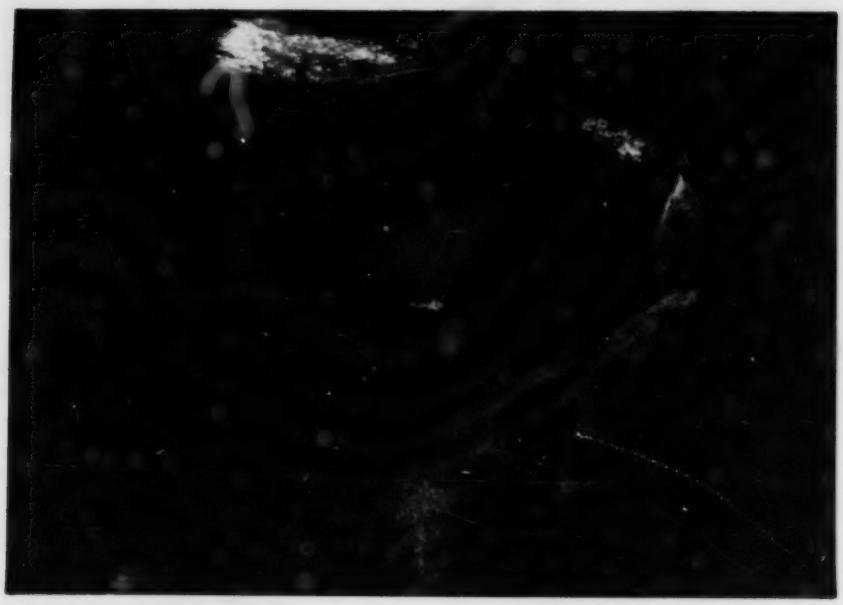
The **Canadian Parks Service, Environment Canada** became concerned for the safety of their Nahanni Butte warden station, due to a massive landslide three km northeast of the station on July 8 (see location on Figure 9). The slide occurred when large amounts of water entered mountain slope sediments during the storms, increasing pore water pressures and reducing cohesion (Claque, 1988).

Small shallow failures of the gentler slope directly above the warden station indicated that this slope was also unstable during periods of heavy rainfall. The danger of a major slope failure in 1988, and previous flooding of the Parks compound at the confluence of the South Nahanni and Liard rivers, contributed to the decision to close the station, as detailed in the park management plan. Events in 1988 resulted in accelerated staff relocation to Fort Simpson, at minimal additional cost. Actual Parks expenditures totalled $5,500, including $1,500 for a geotechnical assessment of the hazard of a slope failure at the station, and $4,000 to evacuate staff and their families to Fort Simpson (S. Langdon, 1991, personal communication).

Based on the above information, the **total cost of 1988 flood damages** is estimated at over $6 million. Much of the damage would have occurred irrespective of better warnings of the magnitude and timing of the floods. Nevertheless, several organizations, including Esso Resources, GNWT ferry and highway operations, and the Canadian Coast Guard, have indicated that damages could have been reduced by more timely warnings of flood conditions.

8a) Salvage efforts in progress to remove fuel and containers from NTCL's Norman Well's dock. Note Esso Resource's drilling islands in background.

(Photo courtesy of A.M. Tout, IPL)



8b) Exposure of oil pipeline on south side of the IPL (Interprovincial Pipe Line) crossing at Ochre River.

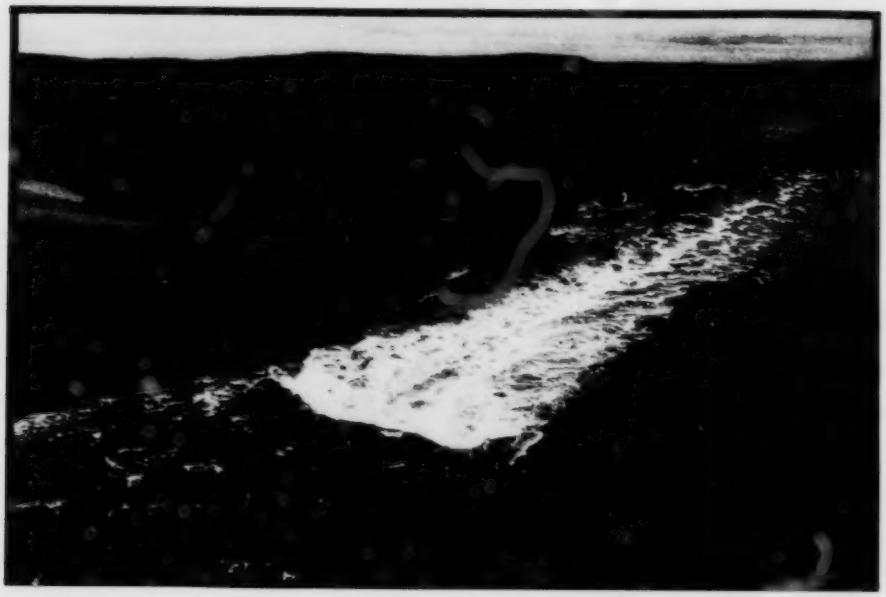
(Photo courtesy of IPL)

Figure 8. Photographs illustrating 1988 flood damages.

8c) Interprovincial Pipe Line Hodgson Creek crossing prior to floods. (Photo courtesy of IPL)

8d) Similar view of Hodgson Creek after 1988 floods, showing guidebank washout. (Photo courtesy of IPL)

Figure 8 (cont'd). Photographs illustrating 1988 flood damages.



8e) Washout of Liard Highway Poplar River crossing on July 3, 1988. Original installation was twin 5.5 m diameter culverts.

(Environment Canada Photo)

8f) Reconstruction of Poplar River crossing on July 26, 1988.

(Environment Canada Photo)

Figure 8 (cont'd). Photographs illustrating 1988 flood damages.

8g) Washout of Liard Highway roadbed on July 2, 1988.
(Environment Canada Photo)

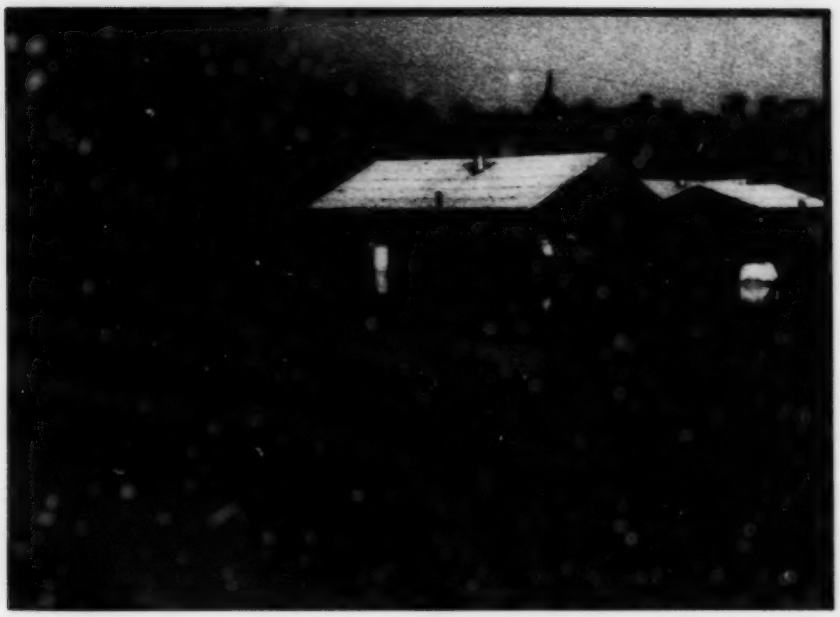
8h) Heavy debris jam and high flows at Upper Blackstone River crossing of the Liard Highway on July 1, 1988.
(Environment Canada Photo)

Figure 8 (cont'd). Photographs illustrating 1988 flood damages.

8i) View downstream at Sahndaa Creek Mackenzie Highway crossing, showing massive debris jam on July 5, 1988.
(Environment Canada Photo)

8j) Heavy debris in the Liard River on July 12, 1988, which removed many of the Coast Guard's Mackenzie River navigation buoys. (Environment Canada Photo)

Figure 8 (cont'd). Photographs illustrating 1988 Flood Damages.

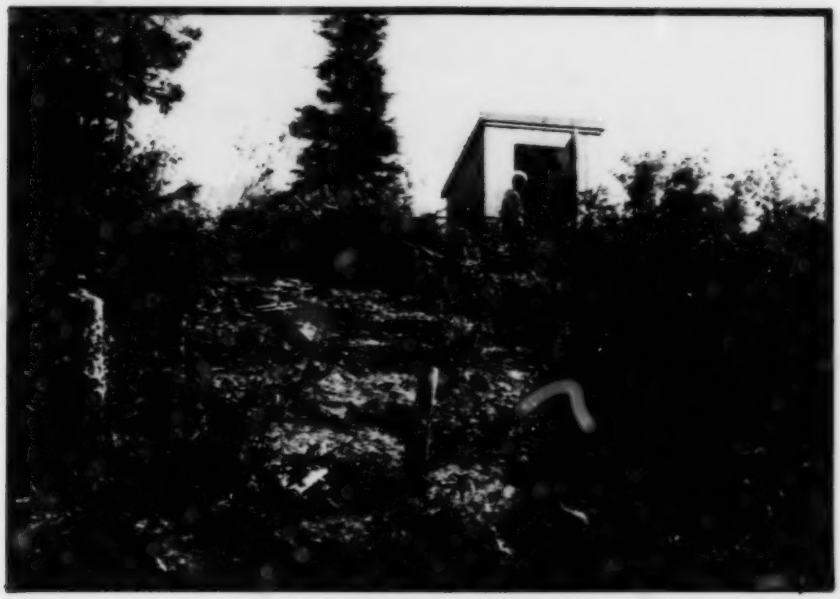


8k) Minor flooding in Nahanni Butte on July 18, 1988.
(Photo Courtesy of E. Bussey, GNWT)

8l) Erosion of Mackenzie River banks at Fort Simpson in August 1988. (Environment Canada Photo)

Figure 8 (cont'd). Photographs illustrating 1988 flood damages.

8m) IWD's former Wrigley River gauging site on July 6, 1988, showing extensive bank erosion (approx. 15 m wide by 100 m long). (Environment Canada Photo)



8n) Bank erosion at IWD's Root River gauging station on July 5, 1988. (Environment Canada Photo)

Figure 8 (cont'd). Photographs illustrating 1988 flood damages.

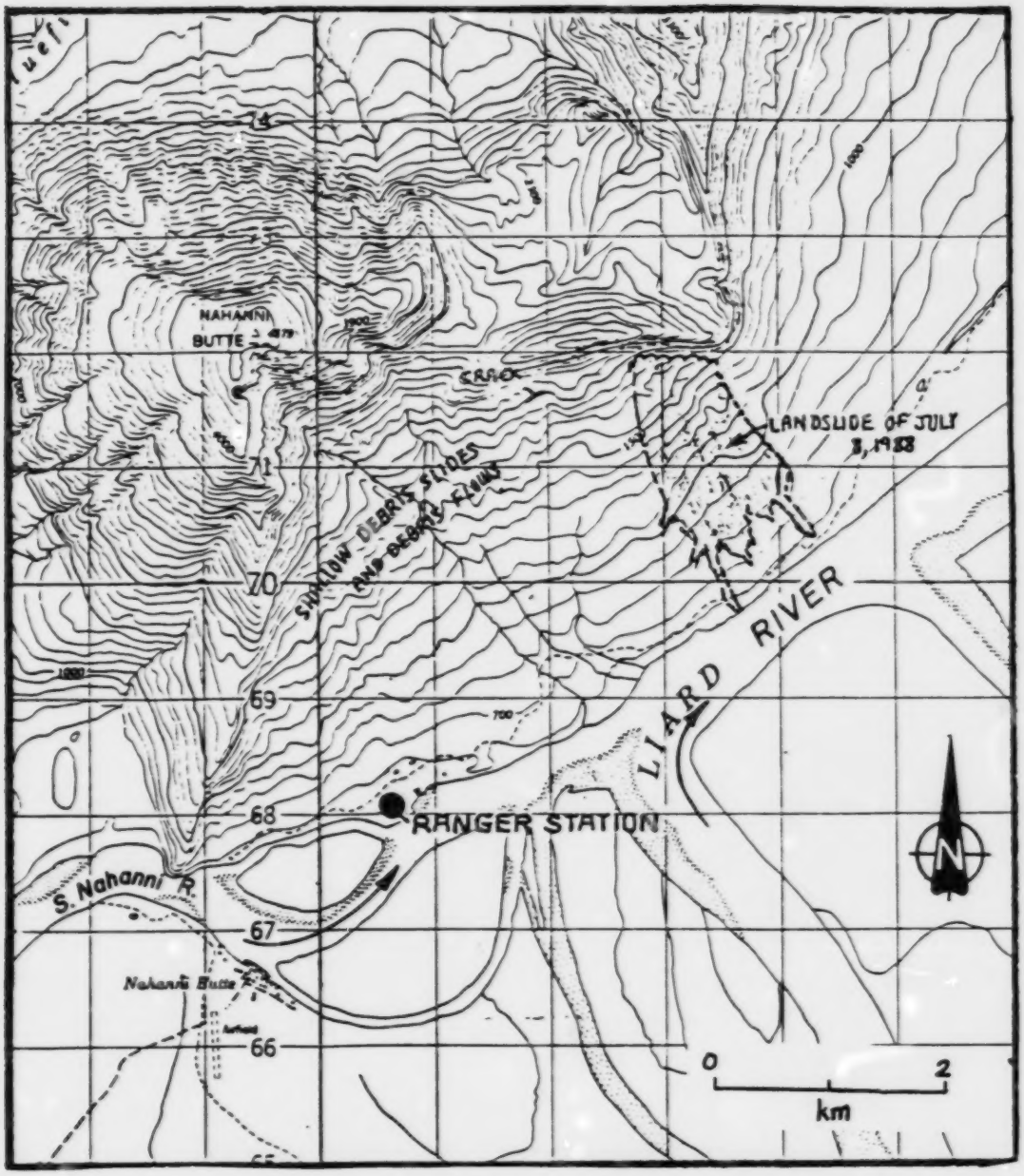


Figure 9. Topographic map showing locations of Nahanni Park warden station and July 8, 1988 landslide (after Claque, 1988).

4.0 FLOOD ANALYSES AND DISCUSSION

4.1 Storm Path and Precipitation

The long-term significance of 1988 floods in the Liard and Mackenzie river basins can be assessed through analysis of the paths, magnitudes and frequencies of meteorologic conditions responsible for the floods, as well as the peak flows themselves.

The areas affected by the two 1988 storms and isohyets (lines of equal precipitation depth) are shown on Figure 10. During the first storm, the areas of highest precipitation were in the mountains west of Nahanni Butte and Fort Simpson, over the Horn Plateau in the Willowlake River basin, southeast of Fort Simpson, and in the upper Hay River basin. During the second storm, rainfall was highest in the southern to northwestern parts of the Liard basin. Burke (1989) provides a complete analysis of the July 1988 storms.

Burns (1973, 1974) and Grey (1981, p. 215) note that major summer storms occur in the Mackenzie Valley due to two primary mechanisms. The first involves incursions of moist air across the Yukon from the northern Pacific Ocean and southward, or southward from the Beaufort Sea down the Mackenzie Valley. The eastern Pacific Ocean and Gulf of Alaska are the second source of storms, through incursions of warm moist air across northern or central British Columbia or from the south, via the northeastern United States into the Liard and southern Mackenzie river valleys. A plot of upper air storm paths during the period 1968-74 obtained from the Alberta Weather Centre, Environment Canada, shows that northward curling of major upper air disturbances is not a frequent occurrence (Figure 11).

The unusual path of the June 28 to July 3 storm resulted in moisture being carried northward into the Liard and Mackenzie river basins,setting the stage for a major precipitation event. Air mass instability, surface-based convective activity, a general upslope circulation, and orographic uplift over the mountains significantly affected total storm precipitation.

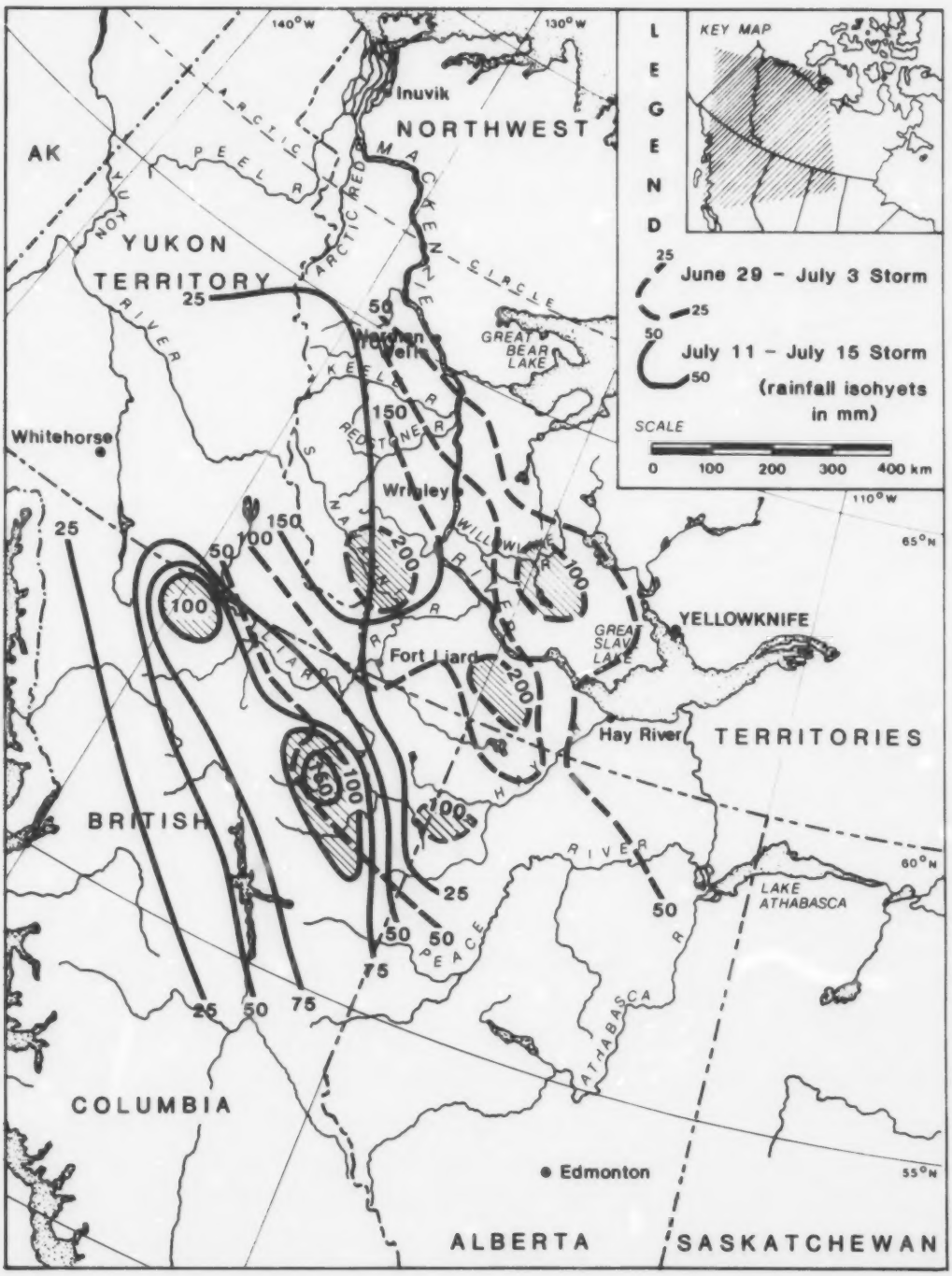


Figure 10. Rainfall depths (mm) for late June to mid-July 1988 storms (based on Burke, 1989).

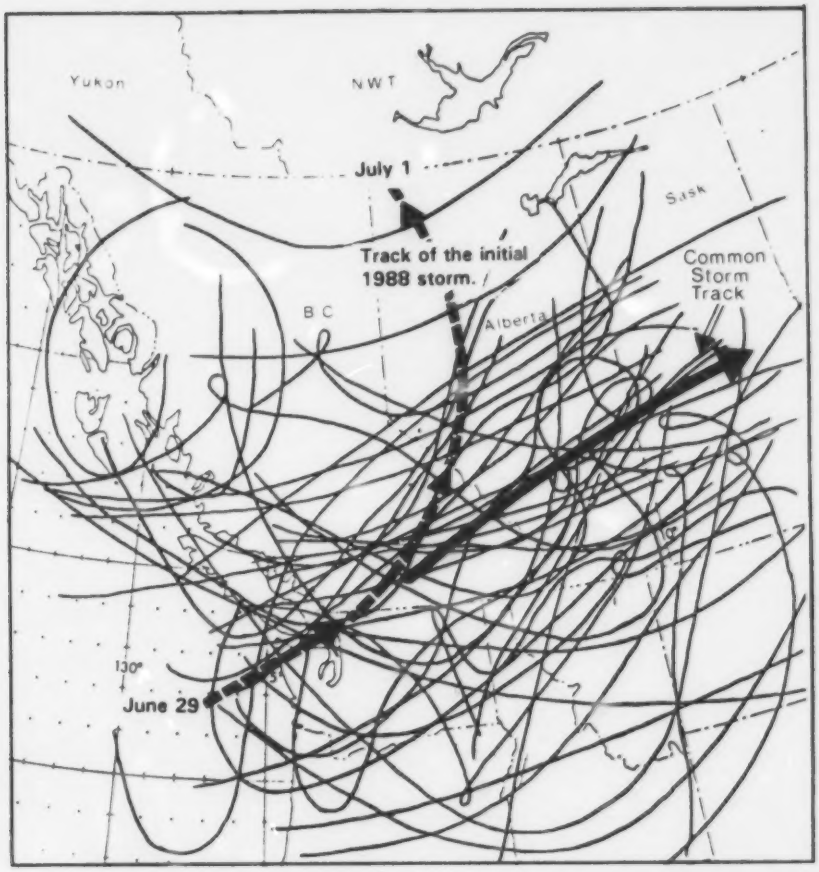


Figure 11. Paths of 50 kPa (mid-atmosphere) storm centres entering Alberta and the NWT from the southwest, 1968-74.

The July 11 to July 15 event fits into a "split low" category, as the main portion of the system continued moving eastward, while a weakened smaller storm centre moved northward. Despite its weaker nature, considerable precipitation fell in some areas.

Previous reports by MacKay et al (1973), Fogarasi (1972), Wedel (1985), and others describe similar storms, mechanisms, and resulting floods in greater detail. Water Survey of Canada streamflow records also clearly show floods resulting from summer storms. Major floods occurred on northwestern Mackenzie Valley tributaries in 1970 and 1974, on the Liard and southwestern Mackenzie river tributaries in 1977, and on south Great Slave Lake and upper Mackenzie River tributaries (including the Hay and

Trout rivers) in 1985.

Difficulties arise in carrying out detailed analyses of 1988 storm data, because the three agencies collecting precipitation measurements in the area use different observation times. The Atmospheric Environment Service (AES), Environment Canada, uses a 24-hour period between two consecutive midnights as a climatologic day, and daily precipitation totals refer to this time period. Precipitation data at Alberta Forestry towers are collected at 08:00 and 13:00 MDT daily, with the climatologic day beginning and ending at 08:00 MDT. Precipitation recorded overnight is then attributed to the previous climatologic day. The Forestry Division, NWT Department of Renewable Resources, also collects precipitation measurements at 08:00 and 13:00 MDT, but uses a climatologic day ending at 13:00 MDT each day. A common time period for daily precipitation observations would greatly assist analyses of storm precipitation data.

Data for area weather stations are summarized in tables 1 and 2. Few weather stations are located in the mountainous source areas of floods, where precipitation can vary greatly over short distances. Accurate estimates of areal precipitation totals are therefore impossible. For example, during the June 29 to July 3 storm the Nahanni Valley station (elevation 175 m) recorded a total of 109.3 mm of rain, while a short distance away, the Nahanni Butte station (elevation 1375 m) reported a total of 259.6 mm, 2.4 times as much (Table 1, Figure 4).

June 1988 precipitation totals were up to 4 1/2 times the long term averages for the month (see columns 1 and 2 of Table 1). At most stations, total rainfall amounts during the first storm (last column of Table 1) equalled or exceeded 30-year averages for the entire month of July (last column of Table 2). Rainfall at upper Liard basin stations also exceeded July averages during the mid-July storm (last 2 columns of Table 2).

The long term significance of the storms can be evaluated by

Table 1. Precipitation in June 1988 and for the June 29 to July 3, 1988 storm.

Station	Mean June Prec. (mm)	June 1988 Prec. (mm)	% of June Normal	Daily Storm Precipitation (mm) Jun 29	Jun 30	Jul 1	Jul 2	Jul 3	Jun 29-Jul 3 Total (mm)
High Level (YOJ)	53.2	78.6	147.7	3.8	47.4	8.6	0.0	0.0	59.8
Rainbow (RT)	63.6	86.8	136.5	24.4	60.8	3.0	2.6	1.6	92.4
Summit	M.M	158.2	M.M	15.0	6.0	36.2	2.4	0.0	49.6
Muncho	60.2	72.8	120.9	8.3	4.8	21.0	1.8	0.0	35.9
Ponton (PO)	63.3	111.8	176.6	31.0	32.8	1.4	0.0	0.0	65.2
Waldin (WU)	94.3	141.8	121.7	35.6	37.2	0.0	0.0	0.0	72.8
Amber (AM)	52.2	148.9	285.2	16.3	47.5	26.9	4.7	0.0	95.4
Adair (AD)	56.4	165.2	292.9	28.2	36.0	11.7	0.5	1.0	77.4
Buffalo (BF)	82.9	92.8	111.9	30.8	43.4	0.0	0.0	0.4	74.6
Basset (BC)	79.0	88.3	111.8	39.4	43.4	1.0	T.R	1.0	84.8
Foggy (FG)	67.5	164.1	243.1	35.2	54.8	0.2	0.0	0.2	90.4
Zama (ZA)	78.5	141.2	179.9	35.0	66.6	4.8	1.4	2.0	109.8
Petitot (PD)	M.M	141.8	M.M	16.0	65.8	15.8	15.0	0.6	113.2
Steen (SV)	62.0	174.5	281.5	24.6	73.4	14.4	2.2	0.4	115.0
Fort Nelson (YYE)	69.1	63.6	92.0	3.6	13.4	42.6	4.8	7.0	71.4
Norman Wells (YVQ)	37.0	63.8	172.4	2.2	26.6	5.8	0.2	0.0	34.8
Border (BORD)	M.M	144.6	M.M	2.2	22.4	13.0	2.0	1.6	41.8
Eagle Ridge (EAGL)	M.M	21.4*	M.M	0.6	8.8	30.2	0.2	2.0	41.8
Fort Norman (ZSN)	47.5	92.4	194.5	0.0	18.8	25.0	0.2	4.0	48.0
Providence (JP)	M.M	73.6	M.M	5.6	9.7	38.1	2.4	1.8	57.6
Cameroon Hills (CMRN)	M.M	186.6	M.M	1.2	33.0	20.4	17.6	10.8	83.0
Hart Lake (HART)	M.M	150.1	M.M	3.4	0.0	42.6	0.2	5.6	51.8
Yellowknife (YZF)	16.8	71.7	426.8	0.8	8.4	2.6	0.0	0.0	11.8
Fort Simpson A (YFS)	38.7	174.4	450.6	3.4	85.8	26.0	16.1	0.0	131.3
Fort Liard (JF)	43.0	139.3	324.0	8.0	27.6	49.0	13.0	5.6	103.2
Tungsten	M.M	M.M	M.M	5.1	**	9.0	6.0	6.5	26.6
Trout Lake (TROU)	M.M	74.0	M.M	0.6	30.2	44.6	13.4	10.4	99.2
Liard Tower (BNTR)	M.M	103.7	M.M	6.6	25.0	54.0	16.6	6.0	108.2
Horn Plateau (HORN)	M.M	153.3	M.M	6.8	26.2	73.0	5.5	0.4	111.9
Mount Gadet (GDET)	M.M	89.0	M.M	1.4	43.2	62.8	10.2	6.4	124.0
Lone Mountain (LOMO)	M.M	128.6	M.M	7.8	30.2	85.4	32.6	2.2	158.2
Redknife (REDK)	M.M	125.0*	M.M	4.4	58.6	78.2	34.6	31.6	207.4
Nahanni Valley (NAVA)	M.M	177.4	M.M	11.9	38.6	50.8	13.4	4.6	109.3
Nahanni Butte (NABU)	M.M	185.2	M.M	30.2	43.6	89.4	85.2	11.2	259.6

* Some data missing ** July 1 total includes data from June 30 M.M missing data T.R trace

Table 2. Daily precipitation totals for the July 11 to 15, 1988 storm.

Station	Daily Precipitation Total (mm) July 11	July 12	July 13	July 14	July 15	Storm Total	30-Year July Mean (mm)
Summit Lake	12.4	53.4	60.2	19.6	8.2	153.4	
Transport Twr (TT)	44.4	57.2	5.2	0.0	6.0	112.8	
Toad River	3.0	16.5	54.6	18.0	2.0	94.1	
Muncho Lake	1.6	17.0	49.4	12.6	0.2	80.8	79.4
Fort Nelson (YYE)	21.8	24.6	11.8	16.4	0.4	75.0	84.3
Watson Lake (YQH)	14.2	31.2	20.8	4.2	0.0	70.4	58.2
Cassier	14.4	35.6	4.0	0.2	2.6	56.8	61.4
Tom Creek	23.4	16.4	3.8	1.2	4.2	49.0	
Tuchitua	13.4	26.0	0.0	1.5	0.0	40.9	60.1
Tungsten (TG)	2.6	2.4	0.0	9.8	25.0	39.8	
Quiet Lake (QL)	8.0	18.0	5.0	3.0	0.0	34.0	46.3
Dease Lake (DL)	2.0	21.4	8.8	2.6	0.0	32.8	55.5
Fort Liard (BN)	0.0	9.5	2.8	0.0	0.0	12.3	89.9
Liard Tower (BNTR)	0.0	10.5	0.5	0.0	0.0	11.0	
Norman Wells (YVQ)	0.0	0.0	0.0	0.0	10.4	10.4	56.1
Fort Simpson A (YFS)	0.0	0.0	0.0	0.0	0.0	0.0	59.3
Nahanni Valley (NAVA)	0.0	20.2	0.2	0.0	0.0	20.4	
Zama Lake (ZA)	T.R	12.4	1.0	2.2	1.8	17.4	90.0
Rainbow	4.2	8.6	2.2	T.R	0.6	15.6	75.7
Nahanni Butte (NABU)	0.0	12.8	0.0	0.0	0.0	12.8	

comparing storm precipitation totals for various periods (eg. 6, 12, 42, and 48 hours) with statistically calculated amounts expected to occur once every 10, 25, or 50 years, on the average. Values are normally calculated statistically from station precipitation data, but are not available for most stations in the study area because the analyses require data from continuously recording precipitation gauges. Forestry fire weather stations use accumulating gauges read only once or twice daily.

Even so, it is note-worthy that the June 30 Fort Simpson rainfall total of 85.8 mm (Table 1) exceeded the amount of 71.7 mm expected in 24 hours once every 50 years on the average (Table 3). The Nahanni Butte station recorded more than 85 mm of rainfall on two consecutive days, indicating greater precipitation in the mountains to the west.

Table 3: Comparison of 1988 storm precipitation to long term meteorological station records.

Station	Antecedent Total Pcp. June 1988 (mm)	Storm Totals (mm) June 29 to July 3 (mm)	Storm Totals (mm) July 11 to July 15 (mm)	24-Hour Precipitation Return Period 10-Year (mm)	25-Year (mm)	50-Year (mm)	Period of Record
Fort Nelson	63.6	71.4	75.0	58.2	69.2	77.5	1966-86
Fort Liard	139.3	103.2	12.3	66.5*	82.9*	95.1*	1966-86
Liard Tower	103.7	108.2	11.0	--	--	--	--
Nahanni Butte	185.2	259.6	12.8	--	--	--	--
Summit Lake	158.2	49.6	153.4	--	--	--	--
Fort Simpson	174.4	132.8	0.0	57.8	57.8	71.7	1969-86
Fort Norman	92.4	48.0	--	--	--	--	--
Norman Wells	63.8	34.8	10.4	50.8	72.9	82.3	1974-86

* 24-hour period fixed as 00:00 to 24:00 Local Standard Time; other storm frequency data from peak tipping bucket gauges rainfall rates for any 24-hour period (such as 04:00 one day to 04:00 the next day).

These data demonstrate that the study area, well-saturated by above-normal June precipitation, was then subjected to two major storms in the following two-week period. Major floods were therefore to be expected.

4.2 Flood Magnitude and Timing

At the time of the mid-1988 storms, 25 stream gauging stations were operating in the Northwest Territories portion of the affected area (Figure 1). Above-normal precipitation in June had produced high watershed soil moisture conditions and flows well above long-term June averages at many stations. At least 16 of the 25 stations listed in Table 4, especially those in the smaller basins, exceeded their long-term average June flows in 1988.

The peak flow of a watershed is considered the best single indicator of the magnitude and significance of floods. While maximum instantaneous flows are commonly analyzed, particularly for small flashy rivers, these are not available for all watersheds for 1988 and other years. Maximum mean daily flows have therefore been used in this report.

Peak flow data for all stations prior to and including 1988 are listed in Table 5. Virtually all of the small- to medium-sized tributaries of the Liard River and the mountainous tributaries of the Mackenzie River as far north as Norman Wells exceeded their historic peak flows. Most of the less responsive Mackenzie River tributaries draining flatter terrain, with significant lake or other basin storage, also experienced record flows.

Table 6 shows the distribution of past maximum annual peak flows for each river basin over the spring and summer months. For most stations, peaks occurring after June 15 are caused largely by rainfall events without assistance from preceding snowmelt or ice jams. The table shows that stations draining flat terrain rarely experience summer rainstorm peaks exceeding those of the spring runoff period. Delay of Kakisa River peaks into early summer is

Table 4. Comparison of historic June flows to June 1988 flows.

STATION NAME (listed in upstream to downstream direction)	WSC STATION NO.	DRAINAGE AREA (km^2)	YEARS OF RECORD	MEAN JUNE FLOWS HISTORICAL (m^3/s)	1988 (m^3/s)
1) Hay River near Hay River	070B001[1]	50,300	26	254	605
2) Kakisa River at Lake Outlet	07UC001[1]	15,600	25	102	214
3) Trout River at Hwy #1	10FA002[1]	9,270	20	105	159
4) Jean Marie River at Hwy #1	10FB005[1]	1,310	17	9.01	23.0
5) Harris River near Mouth	10GC002[1]	701	17	2.54	8.68
6) Liard River at Fort Liard	10ED001[2]	219,600	23	5,460	7,190
7) Rabbit Creek above Fort Liard	10ED006[1]	93	5	0.247	2.32
8) South Nahanni R above Clausen Ck	10EC001[2]	31,100	20	1,370	1,160
9) Birch River at Hwy #7	10ED003[1]	542	15	2.64	11.0
10) Liard River near Fort Simpson	10ED002[2]	274,500	17	7,370	9,470
11) Mackenzie River at Fort Simpson	10GC001[1]	1,306,500	29	13,900	15,800
12) Martin River at Hwy #1	10GC003[3]	2,050	17	14.8	39.8
13) Sahndaa Creek	10GC005[3]	251	7	3.27	4.95
14) Root River near mouth	10GA001[2]	9,820	15	220	278
15) Willowlake River above Metahdali	10GB006[1]	20,500	14	156	213
16) Wrigley River near the Mouth*	10HB003[2]	1,230	12	N/A	N/A
17) Silverberry River at Little Dal	10HB004[2]	1,420	9	77.9	56.1
18) Redstone River 63 Km above Mouth	10HB005[2]	15,400	14	403	507
19) Big Smith Creek	10HC003[3]	964	16	13.5	13.0
20) Johnny Hoe R above L Ste Therese	10JB001[1]	17,270	20	125	122
21) Mackenzie River at Norman Wells	10KA001	1,590,000	27	17,000	19,100
22) Carcajou River below Imperial R	10KB001[3]	7,400	13	234	154
23) Mountain River below Cambrian Ck	10KC001[2]	11,100	15	434	395
24) Mackenzie R above Arctic Red	10LC014	1,680,500	15	21,400	21,000
25) Mackenzie River, E Ch at Inuvik	10LC002	-	15	481	457

1. River draining mainly flatter muskeg or lake controlled basin.
2. River draining mainly mountainous basin.
3. River with mountainous headwaters and flat poorly-drained lower basin area.

* Station destroyed by flood

Table 5. Comparison of previous historic maximum daily peak flows to July 1988 flood peaks.

STATION NAME (listed in upstream to downstream direction)	WSC STATION NO.	MAXIMUM DAILY PEAK FLOW PRIOR TO 1988 (m^3/s)	(month/year)	JULY/88 (m^3/s)
1) Hay River near Hay River	070B001	1,350	5/85	1,350
2) Kakisa River at Lake Outlet	07UC001	196	6/79	359
3) Trout River at Hwy #1	10FA002	522	5/82	614
4) Jean Marie River at Hwy #1	10FB005	90.6	5/76	212
5) Harris River near Mouth	10GC002	48.3	5/85	62.3
6) Liard River at Fort Liard	10ED001	14,200	6/77	14,300
7) Rabbit Creek above Fort Liard	10ED006	7.9	5/82	19.8
8) S. Nahanni R. above Clausen	10EC001	3,540	6/63	2,170
9) Birch River at Hwy #7	10ED003	81.3	5/79	306
10) Liard River near the Mouth	10ED002	16,100	6/77	16,000
11) Mackenzie R. at Fort Simpson	10GC001	22,900	6/77	22,200
12) Martin River at Hwy #1	10GC003	283	5/82	895
13) Sahndaa Creek	10GC005	39.7	9/82	97.7
14) Root River near Mouth	10GA001	2,240	7/76	5,770
15) Willowlake River/Metahdali	10GB006	1,240	5/82	1,910
16) Wrigley River near the Mouth	10HB003	478	5/85	N/A*
17) Silverberry R at Little Dal L	10HB004	210	7/85	200
18) Redstone R 63 Km above Mouth	10HB005	1,950	6/84	3,390
19) Big Smith Creek	10HC003	143	5/82	48.3
20) Johnny Hoe River	10JB001	646	5/73	224
21) Mackenzie R. at Norman Wells	10KA001	30,300	5/75	33,300
22) Carcajou River below Imperial R	10KB001	1,150	6/84	1,110
23) Mountain R below Cambrian Ck	10KC001	1,140	8/86	762
24) Mackenzie R above Arctic Red	10LC014	34,000	5/75	32,100
25) Mackenzie R, E Ch at Inuvik	10LC002	938	6/86	566

* Station totally destroyed by major washout during June/July 1988 flood.

Table 6. Distribution of annual tributary peaks to 1988.

STATION NAME	WSC NO.	NO. OF PEAKS	MISSING PEAKS	NO. OF PEAKS					
				SPRING		SUMMER			
				APRIL	MAY	JUN 1-15	JUN 16-30	JUL	AUG
1) Hay River near Hay River	07OB001*	27	4	5	15	2		1	
2) Kakisa River at Lake Outlet	07UC001*	25	1			11	11		
3) Trout River at Hwy #1	10FA002*	18	1		13	1	1	2	
4) Jean Marie River at Hwy #1	10FB005*	15	1	1	11			2	
5) Harris River near Mouth	10GC002*	15	1	1	13				
6) Liard River at Ft. Liard	10ED001	42	11	4		10	13	4	11
7) Rabbit Cr above Ft Liard	10ED006*	6			5			1	
8) S. Nahanni R. at Ft. Liard	10EC001	27	3			11	7	5	1
9) Birch R. at Hwy #1	10ED003*	13	1	2	8			1	1
10) Liard R. near Mouth/Simpson	10ED002	15			2	6	1	6	
11) Martin River at Hwy #1	10GC003	15	1		12		1	1	
12) Sahndaa Creek	10GC005	5			3			1	
13) Root River near Mouth	10GA001	13	1		2		3	3	4
14) Willowlake River/Metahdali	10GB001*	11	3		5	1	1		1
15) Wrigley R. near Mouth	10HB003	10	1		4		1	2	2
16) Silverberry River near Dal Lake	10HB004	6	1			1	2	2	
17) Redstone R. 63 km above Mouth	10HB005	21	13		1	2		4	1
18) Big Smith Creek	10HC003	14	4		9	1			
19) Johnny Hoe R above L Ste Therese	10JB001*	18	7		10	1			
20) Carcajou River below Cambrian Ck	10KB001	11	2		1	3	2	1	2
21) Mountain R below Imperial R	10KC001	12	4			1	2	3	2

* Flat, muskeg or lake-controlled basin.

due to the storage effects of Kakisa Lake. Rivers draining the Mackenzie Mountains commonly produce summer peaks, due to their rapid response to rainfall events in the mountains.

The fact that most rivers reached historic peak flows during the July 1988 storms indicates that these storms were unusual. The severity and significance of floods can be assessed through the frequency of their occurrence. Flood frequency is expressed in terms of the percentage chance that a flood will occur in any one year, or as the expected average interval between occurrences (eg. 1 in 100 year flood).

Frequency analyses were performed for selected stations having more than approximately ten years of annual maximum mean daily flows, using Environment Canada's CFA computer program (Water Resources Branch, 1985). Previous IWD studies (Aitken, 1985, 1986; Aitken and Westermann, 1986; and Water Planning and

Management, 1984) have produced frequency analyses for most NWT rivers. Aitken and Westermann (1986) determined that the three parameter log-normal distribution with parameters selected by the maximum likelihood method gave the best results. The same procedures were used for this report, with data sets extended to 1988.

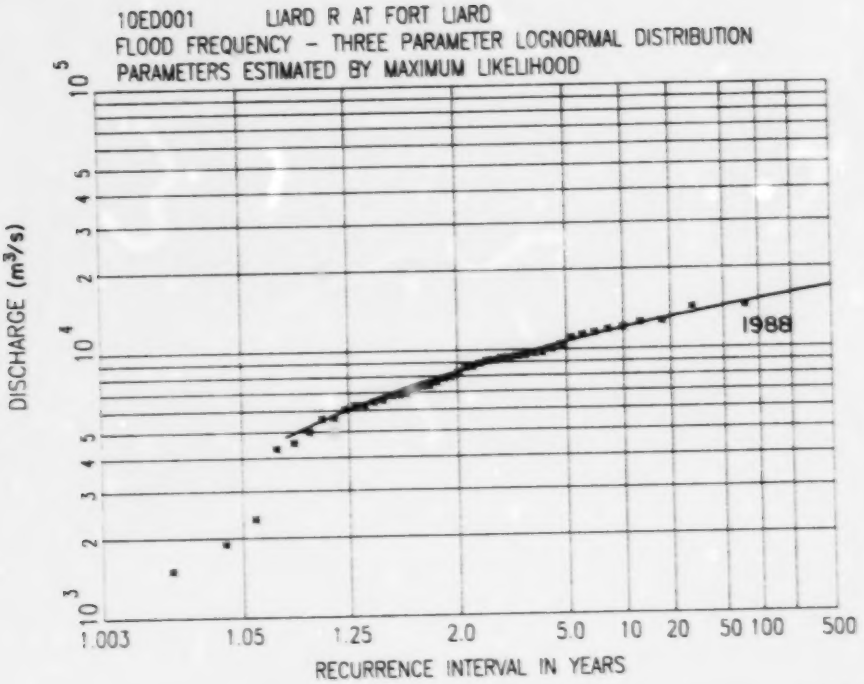
Flood frequency curves for selected rivers are shown on Figure 12, and results for 10-, 100-, and 500-year return period floods are summarized in Table 7.

The 1988 flood peaks plot high on flood frequency curves for most of the rivers draining both mountainous and flatter terrain. The plotting positions for 1988 floods confirm that most rivers from the NWT/Alberta border to Norman Wells produced major floods, regardless of their physical characteristics. Mackenzie River tributaries downstream from Norman Wells did not produce major flows because they were outside the area of high precipitation.

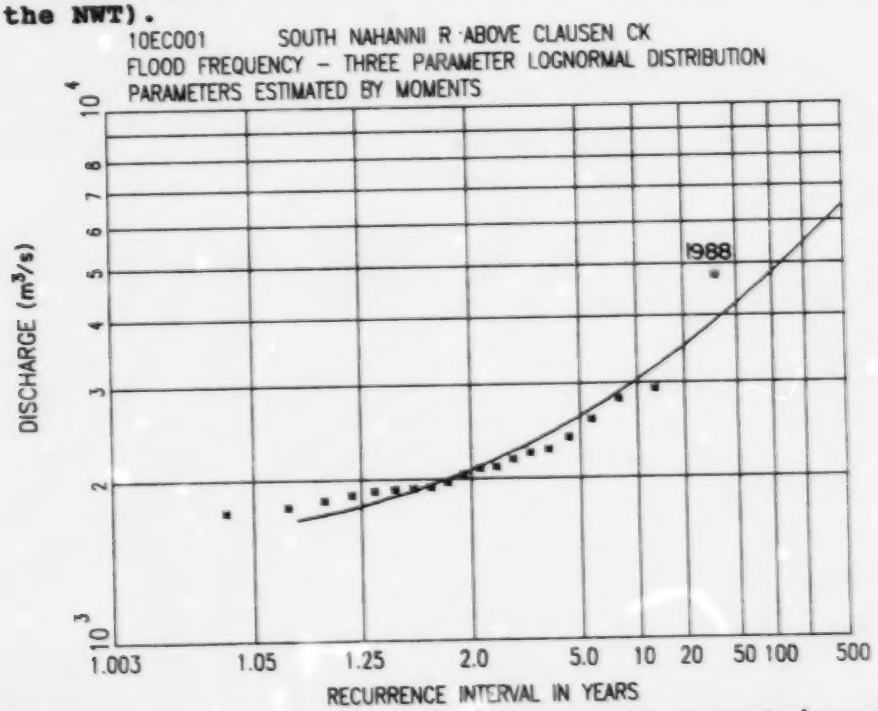
Table 7. Flood Frequency analysis for selected NWT rivers.

STATION NAME	WSC STATION NUMBER	# OF PEAKS USED	DISCHARGE (m^3/s) RETURN PERIOD 10-YR	100-YR	500-YR	JULY 1988 DISCHARGE (m3/s)	RECURRENCE INTERVAL (yrs)
1) Hay River near Hay River	07OB001	26	1,170	1,600	1,880	1,350	20-50
2) Kakisa River at Lake Outlet	07UC001	25	222	368	479	359	50-100
3) Trout River at Hwy #1	10FA002	16	441	798	1,080	614	20-50
4) Jean Marie near the Mouth	10FB005	16	112	253	392	212	50-100
5) Harris River near the Mouth	10GC002	16	53.3	138	233	62.3	10-20
6) Liard River at Fort Liard	10ED001	45	11,900	15,000	16,200	14,300	50-100
7) S Nahanni R above Clausen Ck	10EC001	29	3,320	5,500	7,530	2,170	20-50
8) Birch River at Hwy #7	10ED003	14	123	362	641	306	50-100
9) Liard R. near the Mouth	10ED002	17	15,300	17,200	18,000	16,000	20-50
10) Mackenzie R at Ft. Simpson	10GC001	24	21,600	24,700	26,400	22,200	10-20
11) Martin River at Hwy #1	10GC003	16	292	737	1,210	895	100-200
12) Root River near the Mouth	10GA001	14	3,030	8,650	15,300	5,770	20-50
13) Willowlake River/Metahdali	10GB001	24	1,180	2,040	2,760	1,910	50-100
14) Big Smith Creek	10HC003	13*	125	158	177	48.3	<2
15) MacKenzie R. at Norman Well	10KA001	24*	29,300	34,800	38,100	33,300	50-100
16) Carcajou R below Cambrian Ck	10KB001	13	1,120	1170	1,170	1,110	5-10
17) Mountain R below Imperial R	10KC001	14	1,140	1730	2,260	762	<2

* Two of annual peaks in data sets were estimated; mean daily discharge values used in all analyses.

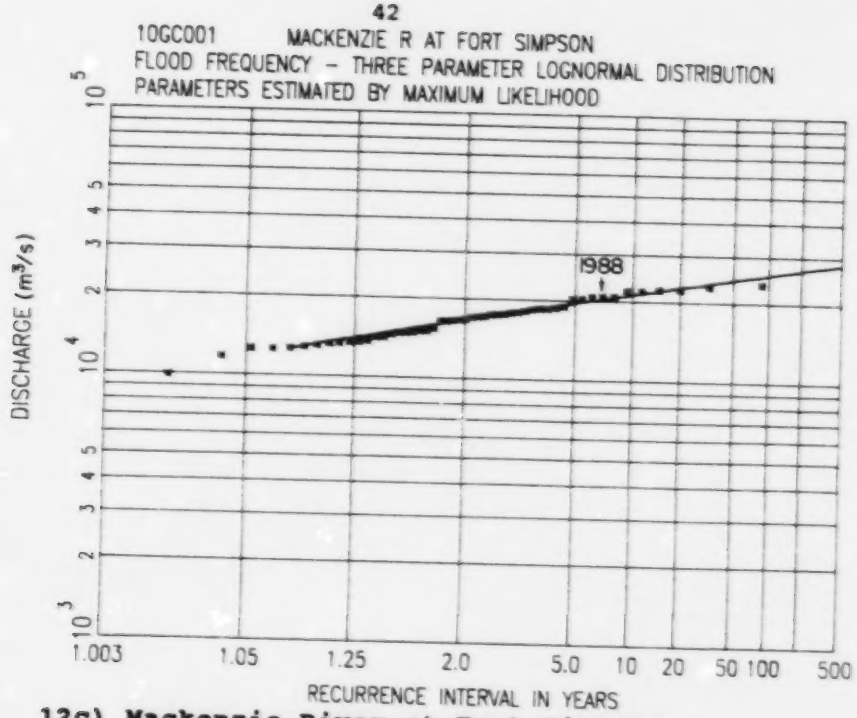


12a) Liard River at Fort Liard (furthest upstream station in the NWT).

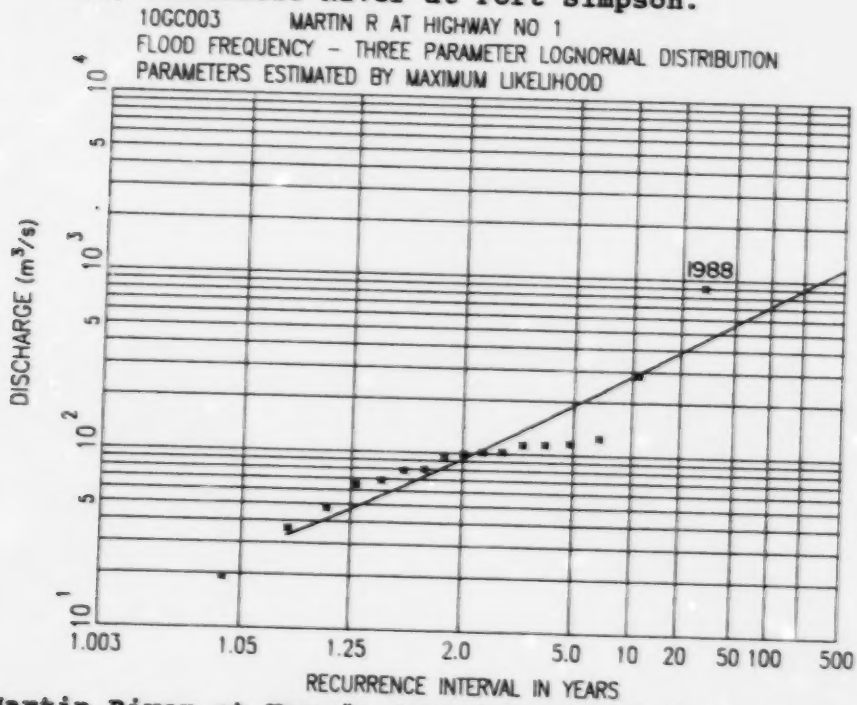


12b) South Nahanni River above Clausen Creek (mountainous basin west of Fort Simpson).

Figure 12. Flood frequency curves for rivers affected by 1988 floods.

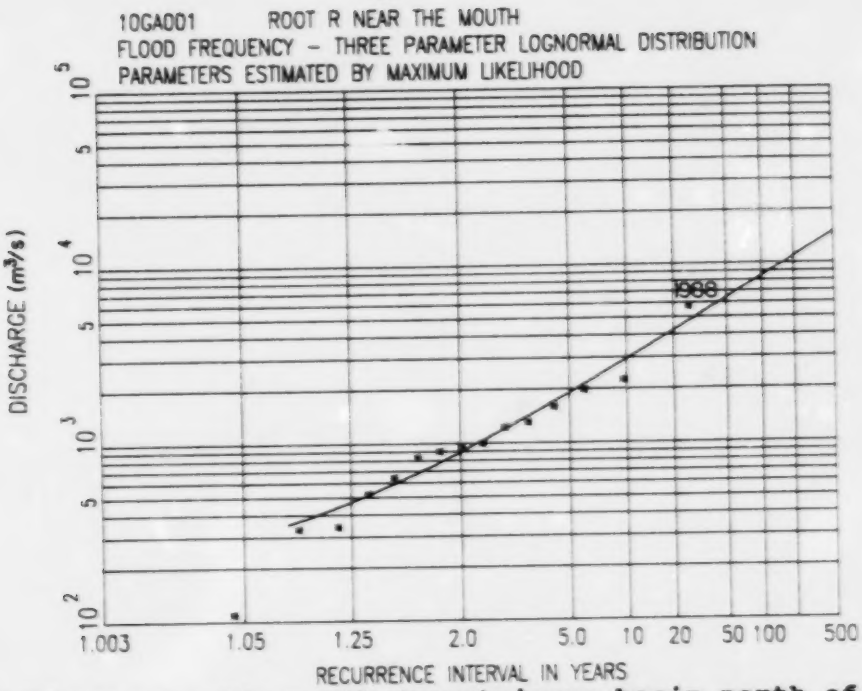


12c) Mackenzie River at Fort Simpson.

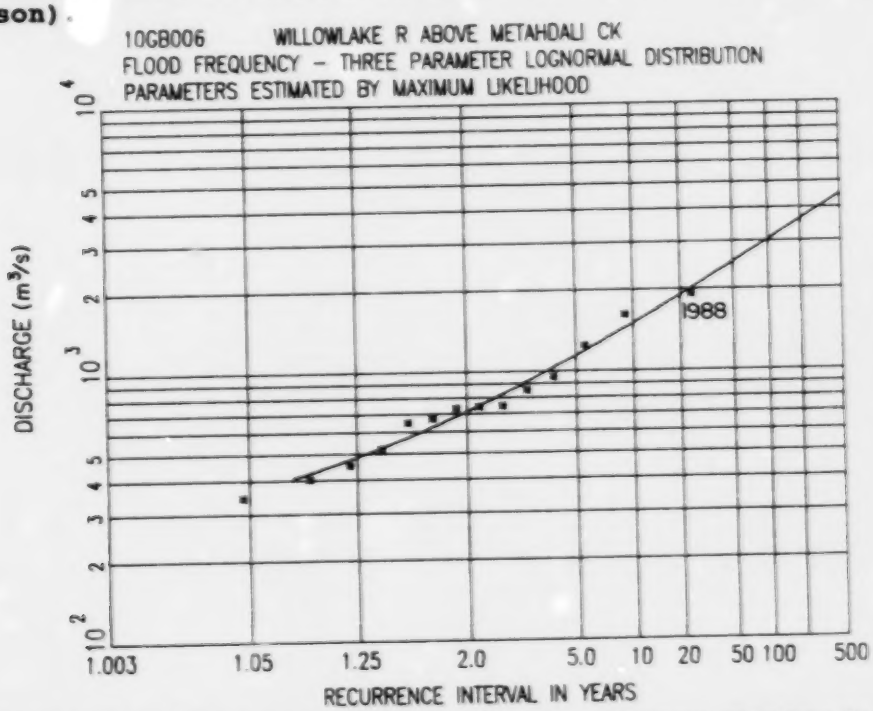


12d) Martin River at Hwy #1 (small basin north of Fort Simpson).

Figure 12. Flood frequency curves for rivers affected by 1988 floods (cont'd).

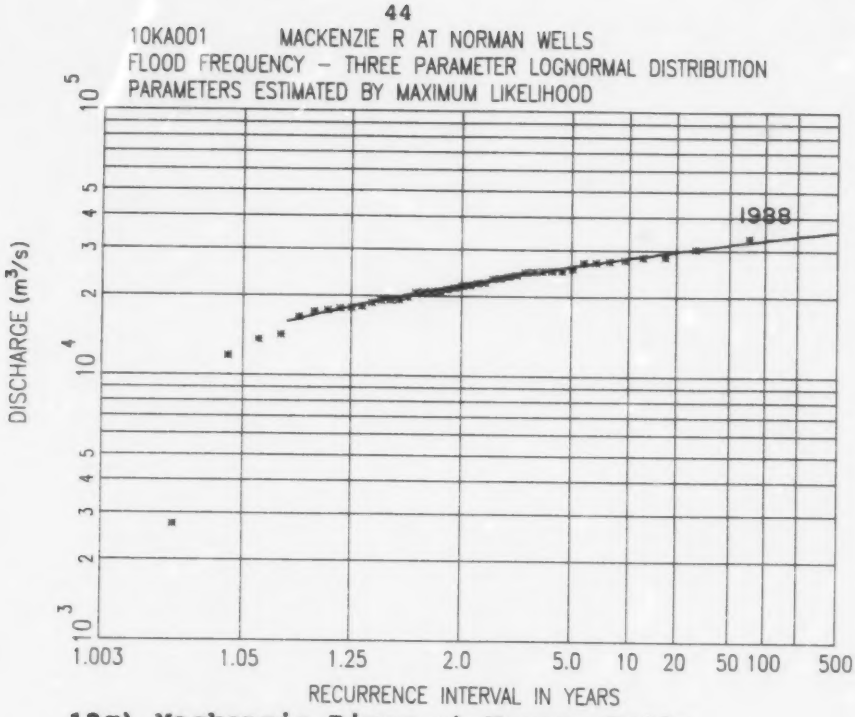


12e) Root River near the mouth (mountainous basin north of Fort Simpson).

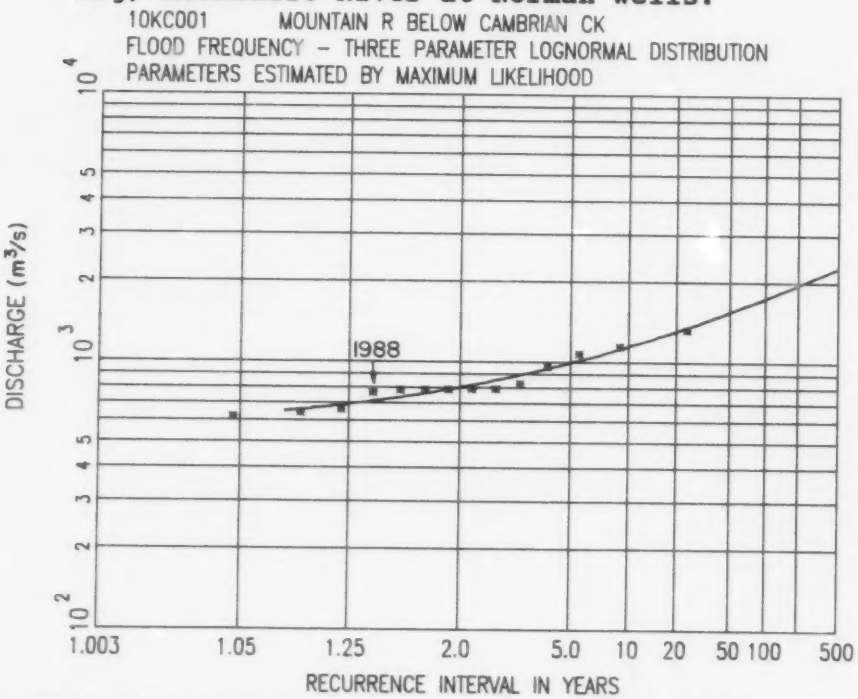


12f) Willowlake River above Methadahli Ck. (large muskeg basin north of Fort Simpson).

Figure 12. Flood frequency curves for rivers affected by 1988 floods (cont'd).



12g) Mackenzie River at Norman Wells.



12h) Mountain River below Cambrian Creek (mountainous basin west of Norman Wells).

Figure 12. Flood frequency curves for rivers affected by 1988 floods (cont'd).

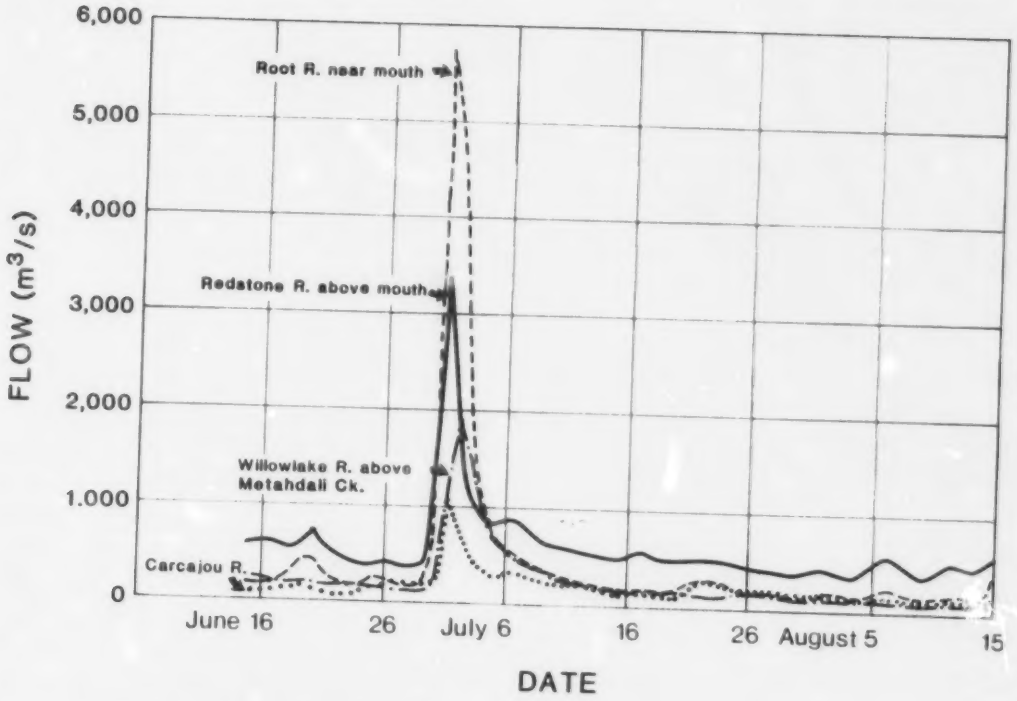
The CFA program also produces a table of the magnitude of floods for different return periods (Table 7), allowing a comparison of 1988 flood values (Table 5) with calculated 10-, 100-, and 500-year floods. These tables show that flood return periods for most stations were in the 20- to 100-year range.

Figure 13 presents hydrographs of mean daily flow data at stations on selected rivers in the study area. The diagram shows the effects of storm timing and path, as well as flood wave travel time and modification of the flood peak as it passed through the basin.

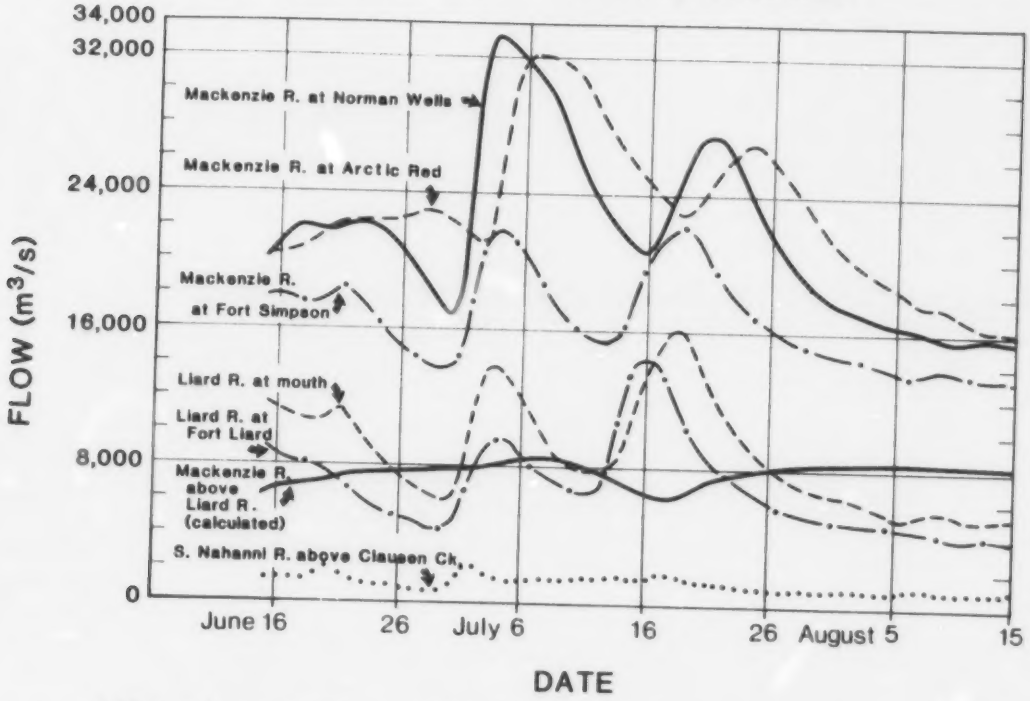
During the first storm, small rivers near Fort Simpson, most tributaries of the Liard and Mackenzie rivers, the Liard River, and the Mackenzie River at Fort Simpson and Norman Wells, all peaked within a few days of each other (on July 3 and 4). Peaks on the Mackenzie River north of the storm-affected area (see Figure 13b) occurred at Norman Wells late on July 3, at Arctic Red River on July 6, and at Inuvik on July 11. Flows calculated for the Mackenzie River above the Liard show only very small increases in July, due largely to the dampening effects of Great Slave Lake.

Figure 13 shows that flood magnitudes increased on the Mackenzie River as far downstream as Norman Wells, then decreased due to channel storage and the lack of major additional downstream tributary inflows.

Peak flows occurred nearly simultaneously on July 3 for all but the smallest tributaries in the area of most intense rainfall (Figure 13b). Flows at Norman Wells also peaked late on July 3, due to the simultaneously arrival of Liard River flows and peak runoff from tributaries north of Fort Simpson. Timing of peak flows at Arctic Red River (July 6) and Inuvik (July 11) show the travel time of the flood from Norman Wells down the Mackenzie River and into the Mackenzie Delta.



13a) Mackenzie River tributary stations.



13b) Liard basin and Mackenzie river stations.

Figure 13. 1988 Liard and Mackenzie river flood hydrographs.

The time required for a major flood to travel through a large watershed is even more clearly demonstrated by streamflow data for the second flood. Most rain fell in the upper Liard basin between July 11 and 13. Flows peaked on July 16 at Fort Liard, late on July 18 at the mouth of the Liard, on July 19 at Fort Simpson, on July 21 at Norman Wells, and on July 24 at Arctic Red River.

Despite its predominantly flat poorly-drained muskeg character, the Willowlake River also experienced historic high flows during the first storm, in contrast to its normal pattern of highest flows during spring runoff.

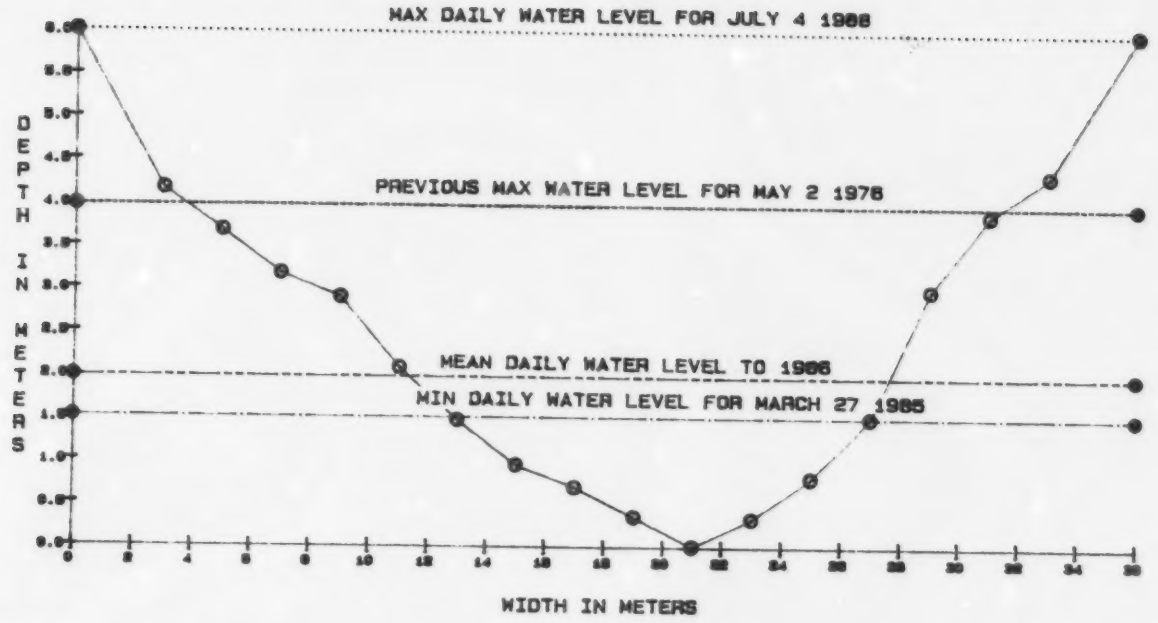
The high water levels recorded at selected gauging stations during the 1988 floods are illustrated on Figure 14. Maximum 1988 water levels are plotted on river cross sections, together with previous historic minimum, average, and maximum water levels.

4.3 Sediment Transport and River Channel Changes

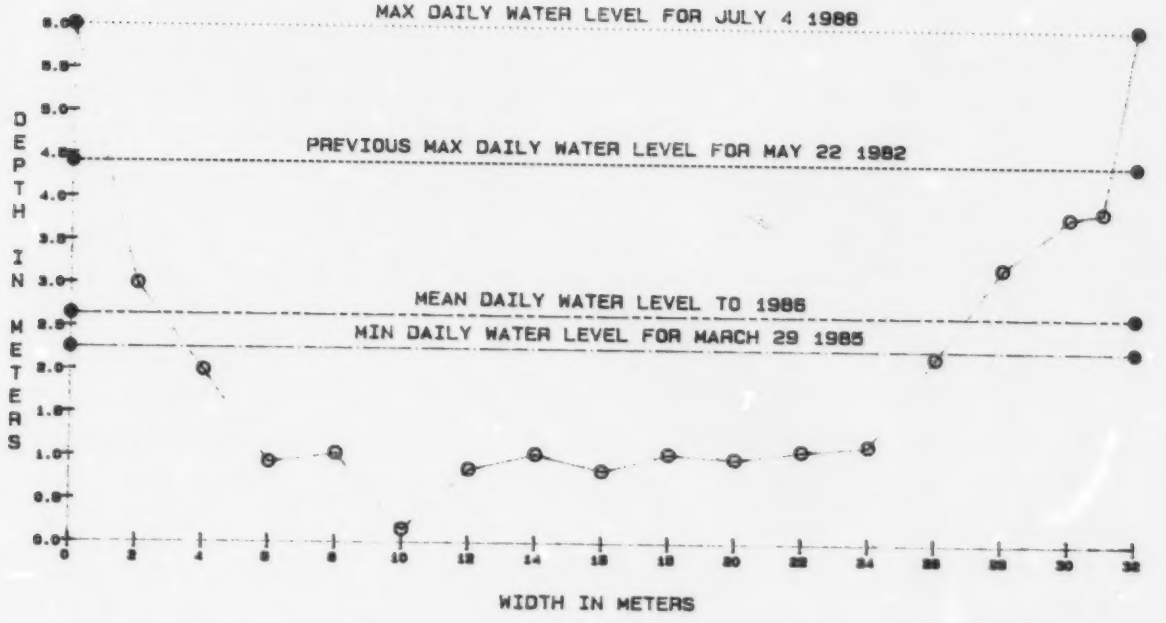
The amount of sediment generated and transported through the Mackenzie River basin and changes in river morphology (channel shape and form) constitute another significant aspect of the 1988 floods.

Heavy metals, hydrocarbons and other contaminants are known to bond to suspended sediment particles in water courses (Nagy et al, 1986). Nutrients attached to sediment particles also play a vital role in influencing the physical, chemical and biological character of the Mackenzie Delta and the near shore Beaufort Sea area (Lewis, 1988; Hirst et al, 1987; and others).

Floods caused by spring breakup and intense summer rainstorm events are the major causes of high sediment loads in the Mackenzie River system, because of increased river erosive power and capacity to transport sediment. During spring breakup, large blocks of moving ice are forced against and erode the banks of the river. Ice jams occur throughout the river system each year

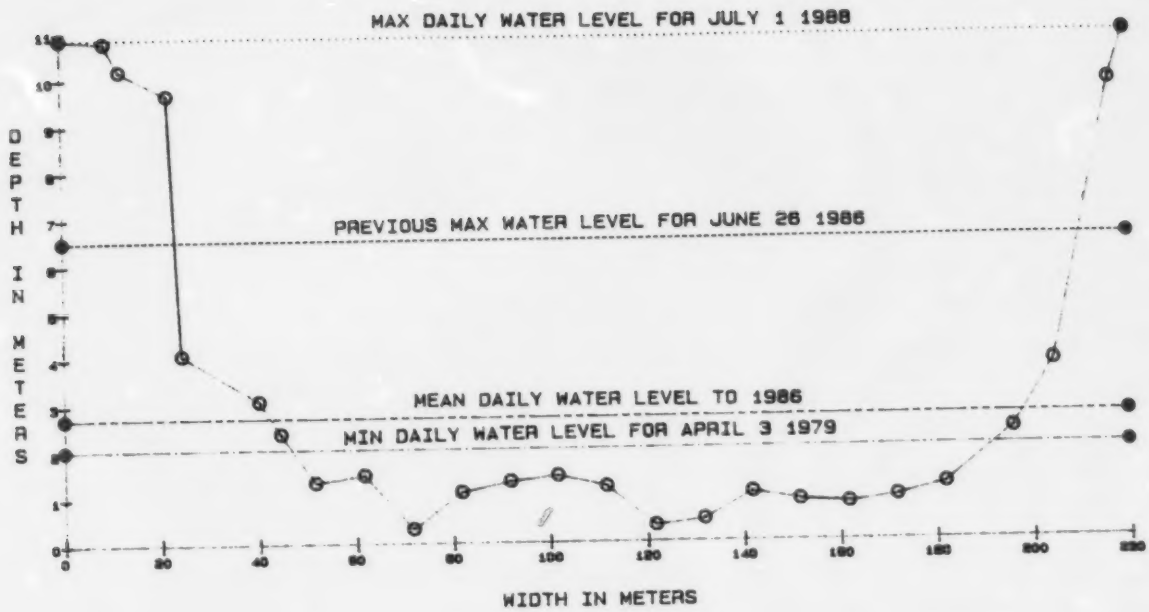

MAX DAILY WATER LEVEL FOR JULY 4 1988
PREVIOUS MAX WATER LEVEL FOR MAY 2 1976
MEAN DAILY WATER LEVEL TO 1986
MIN DAILY WATER LEVEL FOR MARCH 27 1985
DEPTH IN METERS
WIDTH IN METERS

14a) Jean Marie River at Hwy # 1.

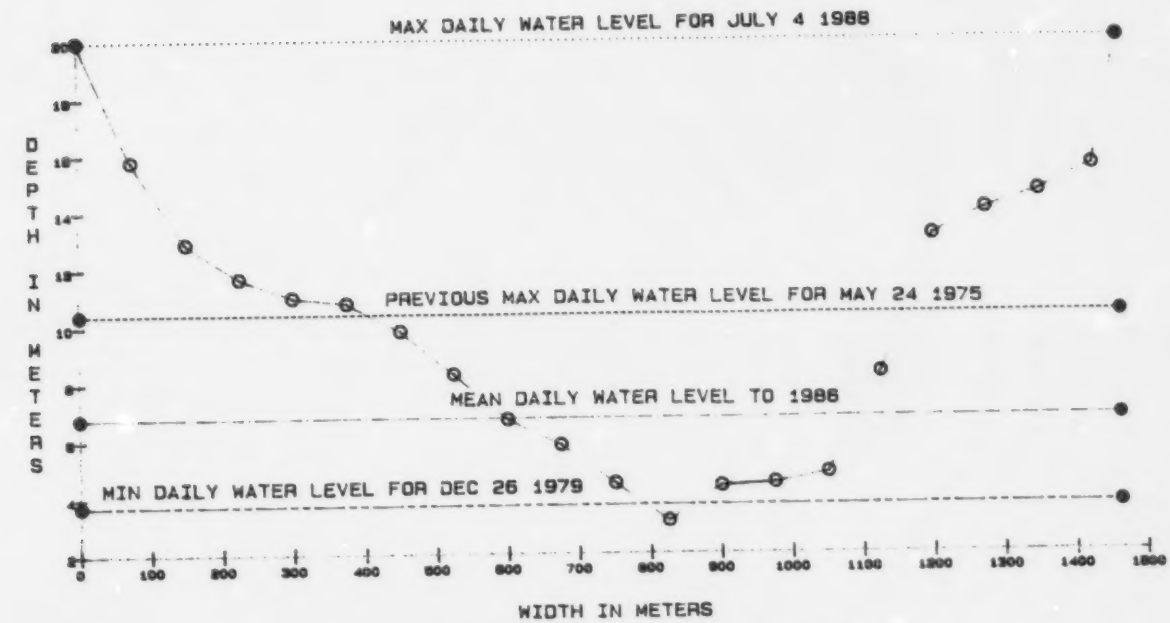

MAX DAILY WATER LEVEL FOR JULY 4 1988
PREVIOUS MAX DAILY WATER LEVEL FOR MAY 22 1982
MEAN DAILY WATER LEVEL TO 1986
MIN DAILY WATER LEVEL FOR MARCH 29 1985
DEPTH IN METERS
WIDTH IN METERS

14b) Martin River at Hwy # 1.

Figure 14. River cross sections showing 1988 flood and previous historic water levels.


MAX DAILY WATER LEVEL FOR JULY 1 1988
PREVIOUS MAX WATER LEVEL FOR JUNE 26 1986
MEAN DAILY WATER LEVEL TO 1986
MIN DAILY WATER LEVEL FOR APRIL 3 1979
DEPTH IN METERS
WIDTH IN METERS

14c) Root River near the mouth.


MAX DAILY WATER LEVEL FOR JULY 4 1988
PREVIOUS MAX DAILY WATER LEVEL FOR MAY 24 1975
MEAN DAILY WATER LEVEL TO 1986
MIN DAILY WATER LEVEL FOR DEC 26 1979
DEPTH IN METERS
WIDTH IN METERS

14d) Mackenzie River at Norman Wells.

Figure 14. River cross sections showing 1988 flood and previous historic water levels (cont'd).

and elevate river stages, allowing the ice to scour the upper levels of the banks. This process contributes large amounts of sediment during breakup, and loosens additional material to be washed away by summer rainstorm events. Summer rainstorms also cause sheet and gully erosion in tributary basins, particularly high-energy mountain streams, contributing further sediment to rivers.

Significant problems arise in determining the sediment loads of rivers, since suspended sediment samples are only collected sporadically or, at most, several times each week. Unlike water levels, a continuous record of the variation in sediment concentration in the water is therefore not available. Full sediment measurements, consisting of depth-integrated samples at five locations across a river, are very time consuming and are made infrequently by IWD staff. These measurements are commonly supplemented with single vertical samples at a representative point in the river cross section.

Standard IWD sediment load computations involve the following steps:

- adjustment of single vertical concentration values to an average for the cross section, using an adjustment factor (k) derived by comparing coincident single vertical and full measurement values;
- calculation of total sediment load for each day using sediment data and hydrograph comparison;
- estimation of sediment loads for single vertical and unsampled days; and
- summing of daily loads to derive monthly and annual totals.

Equations can also be developed for the relationship between river flow and sediment concentration, and used to calculate sediment loads. Use of such equations may be a more feasible approach for sites where low sampling frequencies prevent standard IWD sediment computations.

Table 8. List of active NWT sediment stations.

	Station Name	WSC Station No.	Type of Operation
1.	Hay River near the Mouth	10OB001	Misc.
2.	Flat River near the Mouth	10EA003	Misc.
3.	Liard River near the Mouth	10ED002	Seasonal
4.	Root River near the Mouth	10GA001	Misc.
5.	Redstone River, 63 km above Mouth	10HB005	Misc.
6.	Carcajou River below Imperial River	10KB001	Misc.
7.	Mountain River below Cambrian Creek	10KC001	Misc.
8.	Mackenzie River at Arctic Red River	10LC014	Seasonal
9.	Peel River near Fort McPherson	10MC002	Seasonal

Sediment stations in the NWT network are listed in Table 8. Because sediment data collection and the laboratory analyses of samples are expensive, relatively little sediment data are available for NWT sites. Three of the nine active stations are operated seasonally, while only miscellaneous samples are collected at the other six sites. Major difficulties occur in determining annual sediment loads for all stations, because of the limited amount of data available for even the most frequently sampled sites on the Liard, Mackenzie, and Peel rivers.

During the 1988 flood event, only one of the seasonal stations, the Mackenzie River at Arctic Red River, was thoroughly sampled. This site includes most of the total sediment load contributed to the Mackenzie Delta, the only other significant but relatively minor inputs being the Peel and Arctic Red rivers. Results of July 1988 single vertical sediment sampling and stream gauging for the Mackenzie River above Arctic Red are presented on Figure 15. A rapid increase in sediment concentration, due to the higher river flows, is evident. Previous minimum, average, and maximum concentrations are also displayed.

A number of analyses have been made of Mackenzie River sediment

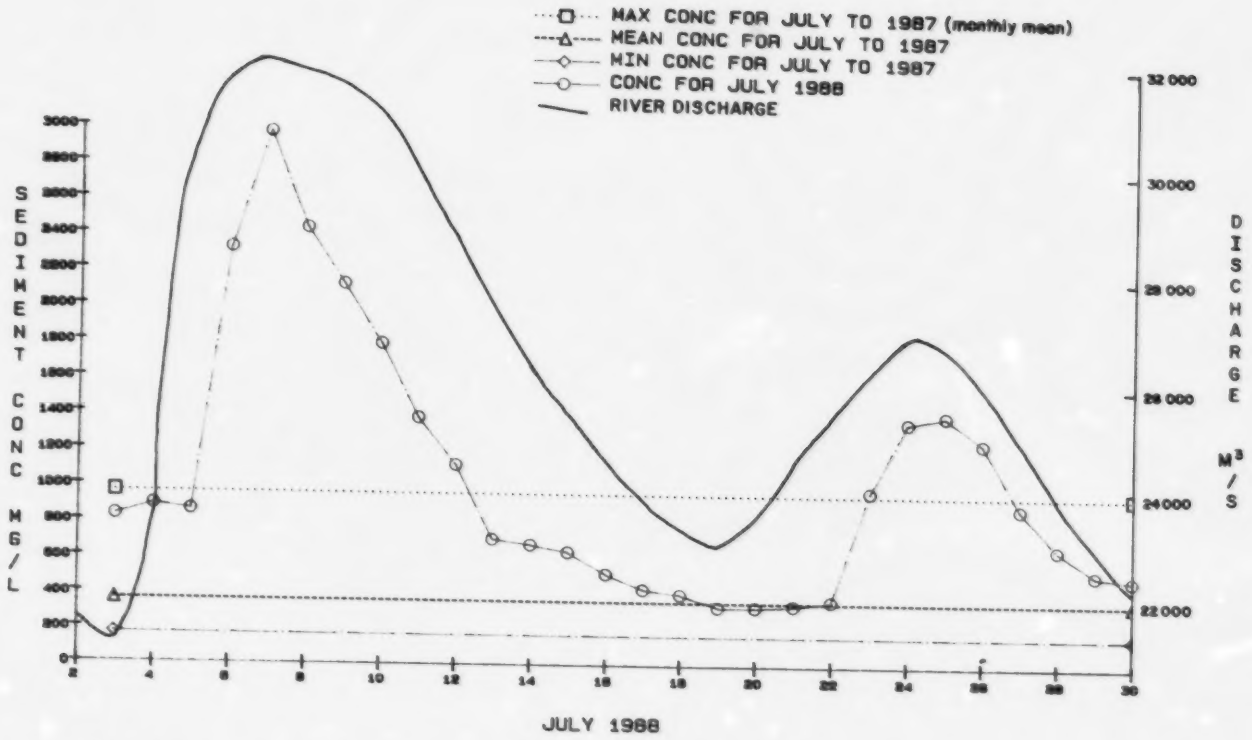


Figure 15. Sediment concentrations and flows for Mackenzie River at Arctic Red River (Station 10LC014) for July 1988.

data. These include IWD-supported studies by Lewis (1987 and 1988), Hirst et al (1987), and Carson (1989 a,b; 1988 a,b,c; and1987). These studies thoroughly evaluated available data and various sediment load computation approaches, and derived revised estimates of total sediment loads. Results are still viewed as approximate, because samples are not collected frequently enough (and not at all during spring breakup) to satisfactorily define natural variability of sediment transport rates over the full range of flows.

A summary of computed sediment load data from various sources (IWD, 1988 a,b; Rogers, 1991 a,b) is presented in Table 9. All of the values must be viewed as estimates, due to the limited data available. The total July 1988 sediment load of the Mackenzie River at Arctic Red was 74.5 Mt (million metric tonnes), compared to previous historic July extremes of 5.1 Mt in 1981

Table 9. Summary of Mackenzie River sediment data.

Sediment Station	Sediment Load (millions of tonnes; Mt)										
	July 1972-88[1]			1988[1]		Average Annual Total			% Delta Input	
	Min	Mean	Pre-1987 Maximum	July	Year	IWD[1]	Range[1]	Lewis[2]	1988[1]	Avg[2]
1. Liard River at the Mouth	1.3	14.9	43.2	26.2	66	50	20-80	52.8	42.0	42
2. Mackenzie River at Arctic Red	5.1	23.0	39.1	74.5	140	100	35-200	88.2	89.2	70
3. Arctic Red River near the Mouth	-	-	-	1.0e	7e	7e	-	7.1	4.5	5
4. Peel River near Fort McPherson	-	-	-	0.5	10e	17e	-	30.5	6.3	24
Total Delta Input	-	-	-	76.0e	157e	124	60-230	125.8	100	100

Notes: e = Estimated 1. Rogers, 1991b 2. Lewis, 1988

and 39.1 Mt in July 1974, and a 1972-88 July average of 23.0 Mt. The historic high summer-month sediment load of 117.7 Mt occurred in August 1974, when persistent rainfall events were recorded in northern Mackenzie Valley tributaries. These storms produced prolonged high flows on area rivers (Jasper, 1976). The value must be viewed with some caution however, as it is based on a few single vertical sediment samples with very high concentrations.

The total July 1988 sediment load for the Liard River near the mouth was 26.2 Mt, compared with previous historic extremes of 1.3 Mt in 1972 and 43.2 Mt in 1974, and a 1972-88 July average of 14.9 Mt. While no sediment data were collected at the station in 1977, it is likely that this second-largest Liard River flood of record, which occurred immediately after spring snowmelt, also produced high sediment loads.

No sediment data are available for 1988 for other area rivers. The significance of sediment transport during the 1988 floods must therefore be assessed against long-term July and annual load figures, from a mainly qualitative perspective. Estimates of average annual sediment loads are provided in the right half of Table 9. The July 1988 Liard sediment load is higher than the long-term July average, but well below the 1974 maximum. The Mackenzie River sediment load was much higher than any previous July total, but well below the summer extreme of 117.7 Mt recorded in August 1974.

The 1988 annual sediment load for the Mackenzie River at Arctic Red River was higher, at about 140 Mt, than the 1972-88 average of 100 Mt, but well below the maximum of more than 200 Mt transported in 1974. When other contributing basins are included, the total 1988 sediment input to the Mackenzie Delta was about 20% higher, at 157 Mt, than the 1972-88 annual average of 124 Mt, but well below the maximum of about 230 Mt.

IWD estimates of the long-term average annual sediment load at Arctic Red River increased as a result of 1988 floods, and are now close to values given by Lewis (1988). This agreement is misleading, as his equations and loads require updating with post-1986 sediment data. Comparison of the various computational procedures by Carson (1988 b and c) demonstrates that the sediment load versus streamflow discharge rating curve approach used by Lewis and others gives higher values than IWD's computational procedures.

At the miscellaneous stations, only a few measurements are made each year over a range of discharges, in order to develop an initial sediment concentration versus discharge relationship. Measurements were made during the 1988 flood event at a number of stations, but until relationships between single vertical and total sediment load and between total sediment load and water discharge are defined, actual sediment loads at these sites cannot be estimated.

Source areas for the 1988 floods can only be suggested, due to the lack of data. The Liard River is estimated to contribute an average of 38% of the total annual suspended load of the Mackenzie River to the Mackenzie Delta (Carson, 1988 b). Only about 3% of this total is estimated to originate from the Mackenzie River upstream from the Liard confluence, due to the effects of Great Slave Lake (Carson, 1988 b). The 1988 storms affected the parts of the Liard and Mackenzie river watersheds believed to be major sources of sediment.

Visual observations of the sediment load of the Mackenzie River upstream from the Liard confluence during the 1988 floods suggest that significant sediment contributions also came from this area. The normally clear line of demarcation between turbid Liard River water and cleaner Mackenzie River water, which often persists as far as 500 km downstream from the Liard/Mackenzie confluence, all but disappeared in July 1988 (P. Wood, 1991, personal communication).

The influx of almost double the previous historic maximum sediment discharge for July, and the erosive power of the 1988 flood, caused significant changes to channels of the Mackenzie River and the Mackenzie Delta. Existing sandbars and thalwegs (deepest part of the channel) shifted, new sandbars were created, and local erosion and slumping of channel banks occurred in the Mackenzie Delta and upstream along the Mackenzie River and its tributaries, affecting river navigation (M. Hansen, 1991 and P. Wood, 1991; personal communications). The channels of small tributaries were also significantly modified by the high flows (Egginton, 1989). Major contributions of sediment from areas outside river channels were demonstrated by the slope failure near Nahanni Butte.

4.4 Forecasting and Flood Warning Services

a) Community Flood Hazards

In May 1979, the governments of Canada and the Northwest Territories signed an agreement on flood damage reduction designed to reduce future flood damages. Flood risk areas in the communities of Hay River, Fort Simpson, Fort Liard, Nahanni Butte, Fort Norman, Fort Good Hope, Aklavik, Fort MacPherson, and Tuktoyaktuk were identified, mapped, and restrictions placed on development in flood prone areas between 1984 and 1988.

In 1988, a joint study by federal and territorial agencies and the University of Alberta was started to develop a basic spring ice jam flood forecast system for Hay River. Results have been encouraging (Gerard et al, 1990, 1989, and 1988), however study costs have been significant, and there are no present plans for similar studies elsewhere.

Nahanni Butte was the only community significantly affected by the July 1988 rainstorms. Other communities are well above summer open water flood levels and are only at risk during spring runoff, when ice jams during breakup can restrict flows and produce water levels well above maximum open-water flood conditions.

Nahanni Butte is situated on the southeast bank of the South Nahanni River near its confluence with the Liard River. Kriwoken (1983) found that flooding has occurred at Nahanni Butte on three occasions since 1921. Previous floods resulted from heavy precipitation during snowmelt runoff. As described in Section 3.3, 1988 flooding was minor and of short duration. A slightly larger flood would have posed a very real hazard to residents, however. Since the only access to the community is by air, major problems could have occurred with the evacuation of residents.

Neither Environment Canada, Indian and Northern Affairs Canada, nor the Government of the NWT currently provide a systematic flood forecasting service for communities in the Northwest

Territories. Environment Canada has, however, provided up-to-date information and advice to the flood prone communities of Hay River, Fort Liard, Nahanni Butte, Fort Simpson, and Aklavik during spring breakup, from field offices in Fort Smith, Fort Simpson, and Inuvik.

Current obstacles to the provision of systematic NWT community flood advisory and warning services are as follows:

- Flood forecasting and warning services have traditionally been a provincial responsibility in Canada, although Environment Canada has usually provided the streamflow data and contributed to development of forecast systems;

- Local IWD field offices cannot provide the same level of information and services after spring breakup because the risk of flooding is lower, floods are spread out over the summer rather than limited to a few weeks during breakup, budgets are limited, and flying to sites is often prevented by poor weather conditions;

- On-going monitoring and forecasting of flood events is time-consuming and requires computer-modelling and other expert activities; and

- An effective forecast system requires development and operation of an effective flood warning system.

Despite these problems, a basic mainstem Mackenzie River water level forecast system was implemented by Inland Waters Directorate in the mid-1960's for the navigation industry. This system is still in operation, providing current and forecast water levels along the Mackenzie River, as described below.

b) <u>Other Downstream Interests</u>

Several other interests besides communities are located along the Mackenzie River downstream of the Liard confluence. These include the Canadian Coast Guard's Mackenzie River navigation-channel and marker-buoy systems; Public Works Canada's docks and wharves; operations of navigation companies such as the Northern Transportation Company Ltd.; Esso Resources' Norman Wells oil field, artificial production islands, docks, and associated facilities; and GNWT Department of Highways' culvert and bridge

crossings and ferries on the Liard River near Fort Simpson, and on the Mackenzie River at Fort Providence and Arctic Red River. These facilities are susceptible to damage and disruption of service when major floods occur.

Environment Canada provides a water level forecasting service along the Mackenzie River navigation system for the open-water (ice-free) navigation season. The purpose of the forecast is to provide the navigation industry and related clients in the Mackenzie River basin with one-, two-, and three-day forecasts of water levels at locations hazardous to navigation and other in-channel facilities. Water levels are forecast at Norman Wells, Sans Sault Rapids, and Fort Good Hope.

Figure 16 shows IWD stations used in the forecast during the 1988 navigation season. Water level data, transmitted from remote sites via satellite or obtained by telephone from observers, were used to subjectively estimate trends in downstream water levels. Further information on the forecast process is available in the 1990 forecast users' guide (Jasper, 1990) and documentation on efforts on forecast automation and use of new streamflow routing procedures (Kerr, 1991).

The accuracy of the forecast during 1988 floods is illustrated by the comparison of one- and three-day forecasts against recorded daily water levels for the Mackenzie River at Norman Wells from June 1 to July 31, 1988 (Figure 17). This manual forecast method was considered acceptable for low water conditions, but underestimates water levels during major floods. Accuracy problems during the 1988 floods were also due to the forecast system being inactive on weekends. Despite these limitations, the forecast has been assumed by users to address high as well as low water conditions.

Following the July 1988 floods, a number of downstream users requested better warnings of high water conditions. Some of the flood damages and remedial work could have been prevented if

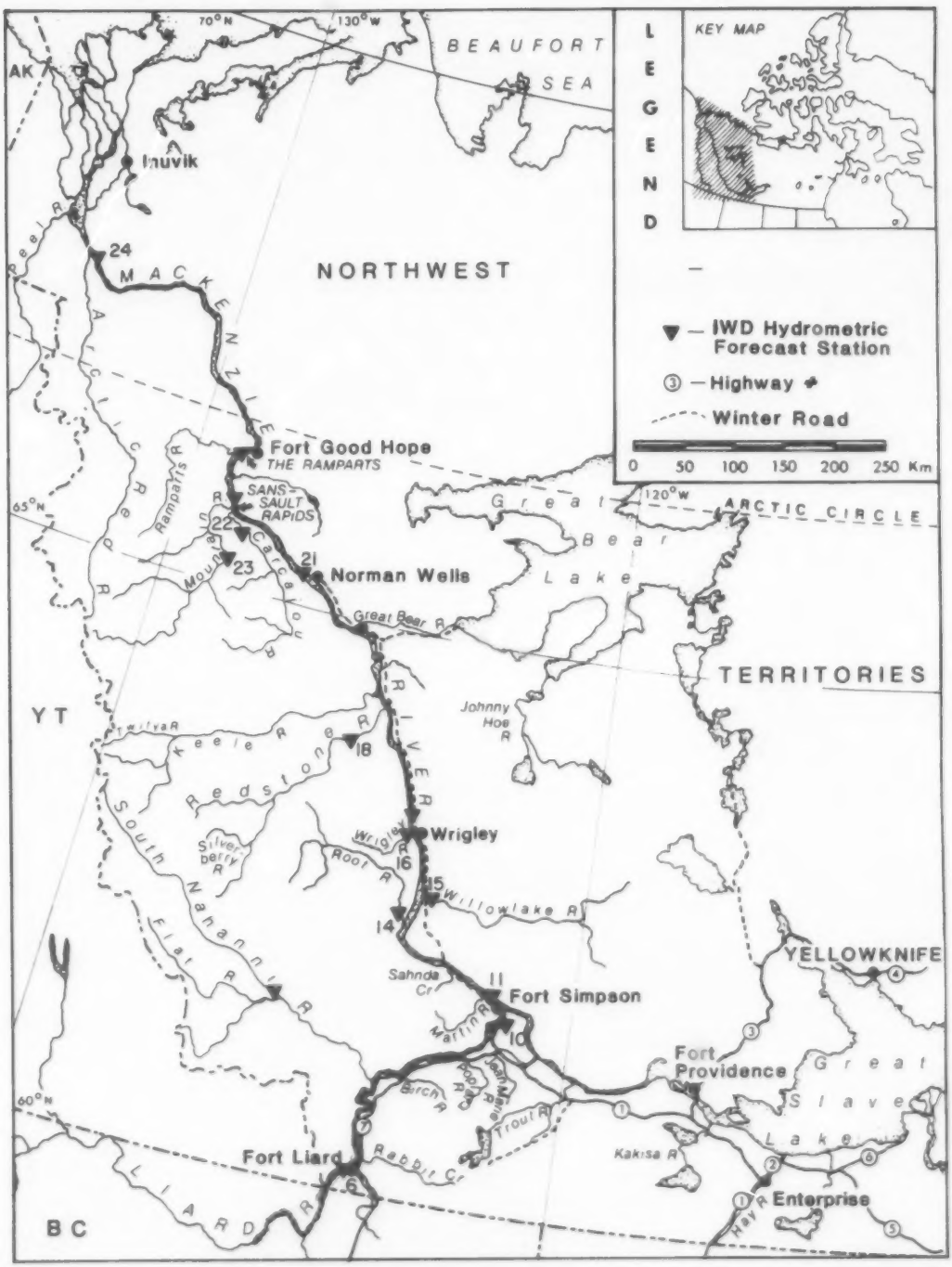
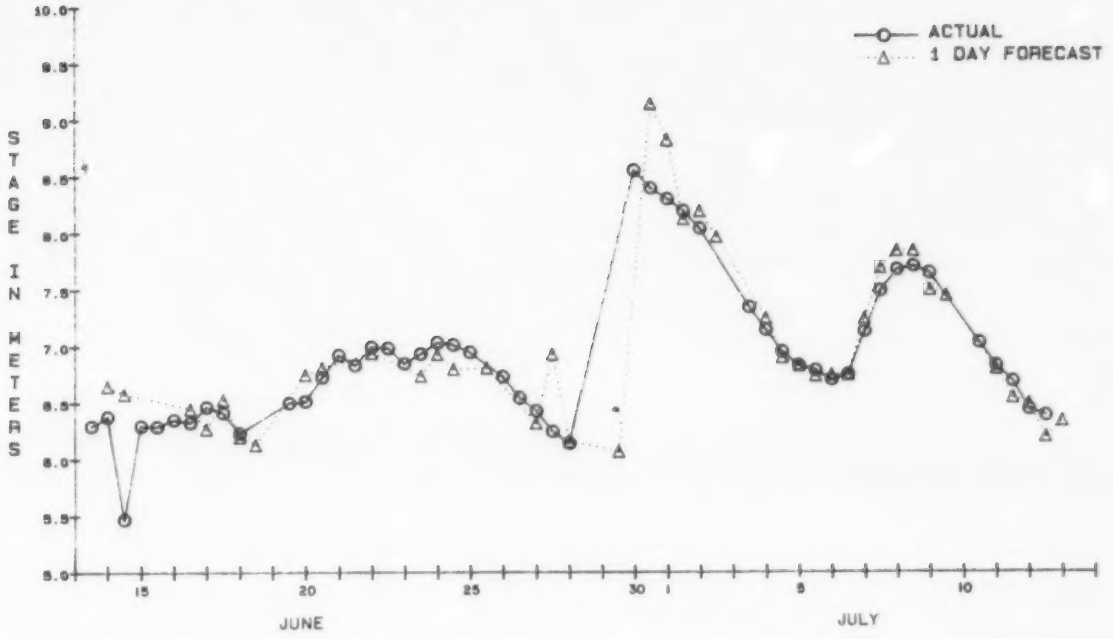
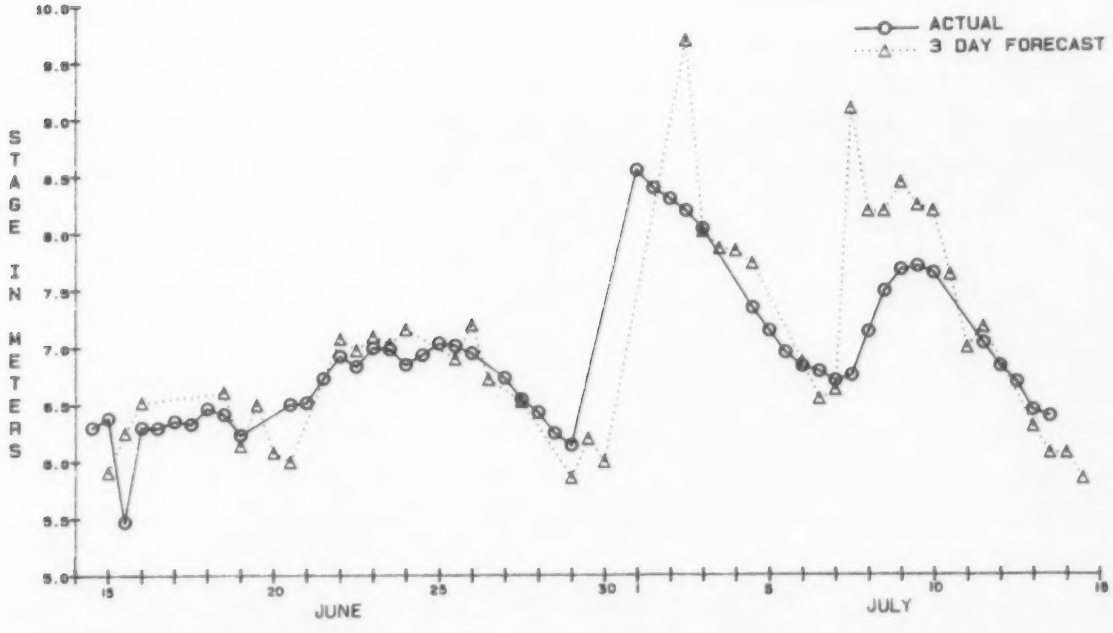


Figure 16. Stream gauging stations used for 1988 Mackenzie forecast. (numbers correspond to stations listed in Table 4).



17a) One-day Mackenzie River forecast.



17b) Three-day Mackenzie River forecast.

Figure 17. Comparison of forecast versus actual (observed) water levels at Norman Wells for June and July 1988.

these users had had 48-, 24-, or even 12-hour warnings of high water levels and major river debris loads. Examples of possible flood damage reduction measures include removal of Mackenzie River navigation buoys before being swept away by high velocities and heavy river debris, removal of trucks, fuel and other material from docks, and protection of in-channel structures.

5.0 CONCLUSIONS

5.1 General

This analysis of 1988 storm and flood events illustrates the impacts of the events on communities, industrial activities, river and highway transportation, and the physical environment of the area.

Provision of real time water resources data, analyzed information, and forecasts of future conditions have been demonstrated to be necessary for safety. Information on high water levels and debris in rivers is needed for the design and operation of river crossings (culverts, bridges, and pipelines), ferries, navigation channels, water intakes, docks, and flood protection facilities in flood-prone areas. Information on low water levels is required for safe and economical navigation, the design and operation of community docks and water supply intakes, and the management of wastewater disposal facilities.

5.2 Flood Damages and Flood Warning Systems

Most of the $6 million of damages suffered during the 1988 floods occurred at stream crossings on NWT highways and along the Norman Wells to Zama Lake pipeline of Interprovincial Pipe Line Ltd. (IPL). Highway damages accounted for half of this total, although the major cost of $2.5 million for installation of a permanent bridge at the Poplar River has been postponed. No assessment has been made of the financial impacts the prolonged closure of the Liard Highway for several months had on the local economy.

The IPL pipeline damages could have resulted in a major pollution incident if the exposed pipe had been ruptured by debris and high flows. Damages suffered by other interests were much lower, but they also produced potential pollution hazards and major inconvenience to area residents.

Municipal officials and the residents of several communities (including Fort Simpson, Fort Liard, Nahanni Butte, Hay River and

Aklavik) receive direct advice and assistance on floods from local IWD field staff. The level of support varies, depending on the anticipated magnitude of flood events, the susceptibility of communities to flooding, IWD field office capabilities, and the gauging network used to assess flood hazards.

Some of the damages which occurred in 1988 could clearly have been reduced by earlier warnings of the floods. The information required includes predicted maximum water levels for flood susceptible locations, the approximate timing and duration of high water levels, advice on other hazards such as debris, and the names of contacts for followup action and further information. Good communication is necessary to warn of flood hazards, provide followup information, and advise on emergency measures.

Useful steps to improve warnings of floods should include the following:

i) Survey river users and other clients regarding flood warning needs, response times required to reduce damages, and comments on the current Mackenzie River forecast service;

ii) Assess the capability of current data collection networks, data bank systems, and forecasting and communication procedures;

iii) Develop options for the improvement of forecasts on the Liard and Mackenzie rivers for consideration by Environment Canada, Transport Canada, and other federal and territorial agencies and major clients; and

iv) Design, implement and operate an improved forecast system, or support agencies assigned these responsibilities.

Experience gained from the 1988 floods supports the following observations on improvements for storm warnings and the navigation forecast system:

i) Atmospheric Environment Service, Environment Canada, provides a Canada-wide regional weather forecast and severe storm warning advisory service. Weather

forecasting is severely limited in the NWT by the low density of meteorologic stations, and their complete absence in mountainous areas which are the sources of major floods. Installation of automatic satellite-reporting weather stations in these areas would assist short range weather predictions and monitoring of storms, but would not improve longer range forecasts produced by numerical climate models (N. Parker, 1991, personal communication).

ii) Installation of four to eight remote unmanned weather stations (as recommended by the MRBC, 1981) would help in making and updating runoff projections for the forecast area. Cooperative arrangements for installation and operation of such stations are already in place in Environment Canada. Some tailoring of available meteorologic data and weather information to river forecast needs would contribute to better forecasting of floods.

iii) The existing navigation forecast system can be significantly improved by automation, and using computer models to route flows downstream. Data retrieval, the plotting and analyzing of information, forecasting future downstream flow conditions, and distributing the forecast would be speeded up, reducing the effort and cost of forecasts. A thorough assessment of the entire forecast process should be completed, followed by system development. The approach used must remain as simple as possible, however, due to the limited data collection network. More complex and accurate forecast techniques can be developed as required and as experience is gained.

iv) The forecast area stream gauging network is considered fairly adequate for the level of forecast involved, but upgrading of several existing sites and construction of a few new sites would be useful. The one-time capital and annual operation costs of these additions are substantial, at approximately $60,000 and $40,000 per year, respectively.

5.3 Sediment and Water Quality

The importance of major flood events in transporting large amounts of sediment, eroding channel banks, and depositing sediment far downstream has been described in Section 4.3. Gill (1971) and others have pointed out the critical role of floods in providing the inputs of sediment and nutrients required for "pulse-stabilized" environments such as deltas. A continuing supply of sediment to the Mackenzie River is critical to the

stability of channels downstream to the Beaufort Sea. Major downstream changes are likely if upstream sediment contributions are altered due to upstream development or climatic change. A northern sediment data base is required to evaluate the direct (physical) and indirect (biological) impacts of floods, and changes in the supply and transport of sediment from source areas.

Recommendations for contaminant and sediment-related programs include the following:

i) An expanded long-term program is recommended at the nine current NWT sediment sampling sites. Miscellaneous sampling should continue, until intensive two- to three-year duration programs at each site can define relationships between river flow and sediment load and concentration;

ii) Event-oriented water quality and sediment sampling is required during major floods to document their major contribution to total annual sediment loads;

iii) Further evaluation of sources, fates, and effects of contaminants bound to sediments is recommended (Carson, 1988 b), to follow up on earlier work (Nagy, 1987; Marsh and Ferguson, 1988). The reworking of river channel sediments during floods may result in remobilization of sediment-borne contaminants from accumulations in depositional areas. The initiative would require expansion of IWD's network of seasonal sediment stations to more Mackenzie River tributaries, and use of specialized sampling and laboratory procedures over a period of years.

5.4 Final Comments

The Liard and Mackenzie rivers are currently used for navigation, ferry crossings, community water supplies, subsistence hunting and fishing, and recreation. An ongoing commitment to inform the public, private-sector interests, and government agencies on river conditions is clearly justified.

IWD has a crucial role to play in providing information on floods, due to its national responsibility for collecting and publishing streamflow data. Indian and Northern Affairs Canada

is responsible for territorial water planning and management services. Various GNWT agencies are responsible for municipal planning, disaster response and assistance, river highway crossings (by road or ferry), and other activities.

Cooperative efforts are needed on the part of all agencies to effectively monitor river conditions, warn clients of hazards, and coordinate responses to emergencies.

Documentation and analyses of extreme storm and flood events need to be continued to provide systematic records of these events, to identify necessary improvements in stream gauging networks and their operation, and to assist in implementing and improving flood warning systems. The reduction of damages from floods must focus on efforts by government agencies, communities, industry, and future developers to better prepare for and respond to similar events in the future.

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